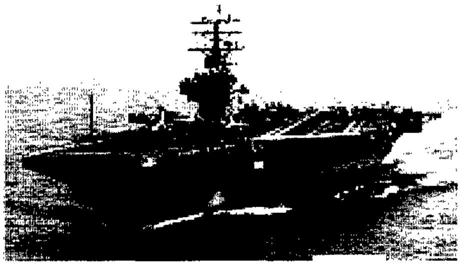

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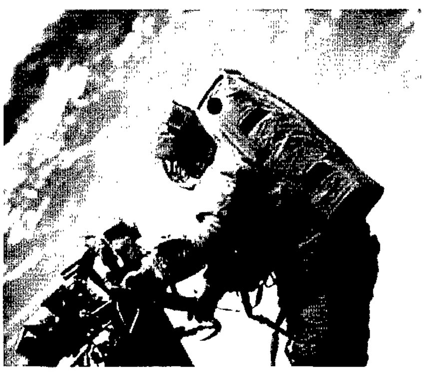

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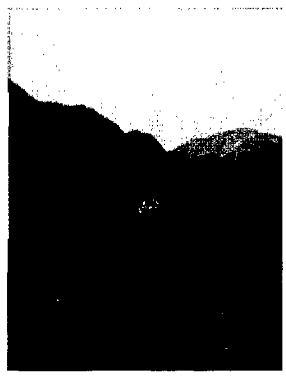

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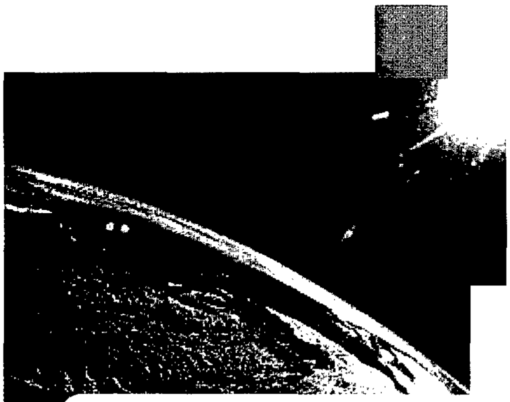

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14. ABSTRACT

The primary objective of the SAFE Association is to stimulate research and development in the fields of safety, survival, and life support. The SAFE Association publishes the SAFE Journal at least twice a year. Table of Contents for this issue:
Degradation of Pilot Reach Under G.
Helicopter Ditching: Time of Crash and Survivability
Evaluation of Acceleration Response During AFRL + Gz Vertical Deceleration
Mathematical Simulation of the Human Ventilatory Response during and Altitude Chamber Physiological Training Profile
First Hand Witnesses of Sled Testing Over the Past Forty Years
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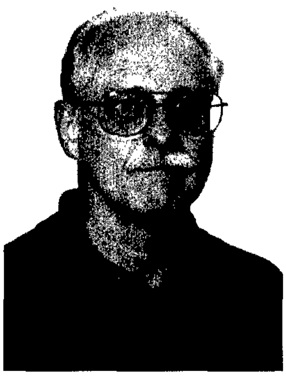
President's Message

Joel Albinowski

2006 SAFE President



Welcome to the Fall Journal. Through the hard work of our dedicated Publications Team, we have before us a varied selection of timely and interesting articles. Whether you have been involved with SAFE for some time or are new to the association and perhaps unaware, I should point out that SAFE is now in its 50^{th} Year!

How things have changed since that auspicious beginning... In 1956 we were in the throes of the Cold War, and now we have a more deadly enemy—terrorism. Travel time from London to New York, was 14+ hours, and the golden age of the jetliner was about to begin. Aircraft ejection seats were beginning their second generation; anti-exposure equipment consisting of a leather jacket and woollies was considered state of the art. Even consider that it could take two weeks for a simple letter to cross an ocean—now we have a system of instantaneous communication available 24/7. The internet was something only a select few in highly technical scientific disciplines had even heard of. In relation to the growth of SAFE through these times we have published a unique and informative historical journal; please peruse it.

In fifty years we have grown from a handful of like-minded individuals concerned with space and flight equipment to over 500 strong members in the disciplines of transportation safety that include industry, military, and academia around the globe. Our corporate sponsorship has grown to over 85 sustaining members. We have matured from a gathering of technologists casually exchanging information, to symposia including dozens of presentations, workshops, lectures, and demonstrations comprising the latest innovations. Our commitment to the preservation of life has not only fulfilled the requirements of the aviation community but has also encompassed the domestic needs of first responders as well as homeland security.

As members of this great association called SAFE, united for the common purpose of safeguarding life, we eagerly face the challenges that the future holds for us. We do this by continuing our participation in the association on a local and international level. The importance of the association to each member goes far beyond the chapter meeting or symposia as we are all at the leading edge of safety design, development, and technology implementation.

It is with regret that I complete my term as president as it has proven to be a challenging and rewarding experience. I sincerely appreciate the opportunity you have given me, and I hope I have fulfilled my duties consistent with your expectations. I sincerely thank all of the members of the Board of Directors for their support and unceasing dedication throughout the year. Also, our organization would not be what it is today without our administrator Ms. Jeani Benton whom we all owe a debt of gratitude. I thank you. Finally, to the incoming president Ms. Christy Cornette I send my best wishes and encouragement for another successful year for SAFE.

I look forward to meeting each and every one of you in Reno!

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ASSOCIATION OBJECTIVES:

The primary objective of the SAFE Association is to stimulate research and development in the fields of safety, survival, and life support. The Association seeks to disseminate information to professionals from industry, government, and education, and to maintain a meaningful relationship with the scientific communities related to safety, survival, and life support.

JOURNAL ARTICLES:

Manuscripts are solicited for two sections of the Journal: Research, Development Test and Evaluation (RDT&E) and the SAFE Forum. Manuscripts in the RDT&E Section may be requested to be peer-reviewed. Peer review is optional. If peer-reviewed and accepted for publication, the article will be so noted. This Journal section presents research data and findings gathered by direct measurement, experimentation, theoretical analysis, or scientific evaluation of operational experience. This section may also include the development, testing, and quantitative evaluation of new or improved systems; design and evaluation aids, and safety, survival, or rescue procedures or equipment. In addition, historical reviews and descriptions of methods and processes involved in unique R&D and procurement programs may be submitted for consideration. The SAFE Forum Section will include Letters to the Editor, News of Members and News of Corporate Members submitted for publication if appropriate. All published media and information is subject to review and edit by the Publication's Staff. All released information that is edited will require a new release approval by the submitting party.

PEER-REVIEW PROCESS:

Acceptance of all manuscripts for publication is determined by the Journal Editor and Publication's Staff. If peer review is requested, a publication decision will be made after their review by at least two anonymous referees selected by the Editor to be competent in the subject matter. Information from other sources also may be used by the Editor to determine the acceptability of manuscripts, request for changes, or rejection.

HUMAN AND ANIMAL STUDIES:

The Journal subscribes to the principles of the Helsinki Declaration for human experimentation. Animal experimentation must be conducted in accordance with the "Guide for the Care and Use of Laboratory Animals" published by the Office of Science and Health Reports of the NIH, Bethesda, MD.

LETTERS TO THE EDITOR:

Voluntary submission of letters to the Editor on issues of interest to the Journal readers is highly encouraged. These submittals will be reviewed and edited as appropriate and assumed to be non-proprietary.

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The SAFE Journal: A New Framework and Creative Process

Mark I. Darrah, Ph.D., SAFE Publications Chair for 2006

Serving this year as Publications Chair has provided a mixture of blessings and an inevitable growing pain, but has fundamentally been a year of transition and growth. The SAFE Journal you now hold in your hands is the first of the year and marks the beginning of what we hope to be a long and valuable series of fine technical documentation from our industry and the Association. The aforementioned "pain" was that the amount of volunteer work completed in revamping the format and publications approval process we use in Journal creation caused the actual publication release date to continue to slip during the year. Despite such setbacks, we now have a re-energized review cycle and associate editors, eager reviewers, and a solid support team to generate the framework for documentation you see before you. Check it out.

The *RDT&E* section represents original works from our members. Each month we will try to provide a sample of the many possible areas of ongoing research that are of value to our readers—especially those that address critical issues. The *Forum* section includes two papers which provide historical and, if I may say so, entertaining looks at our industry's early days. Within this issue's Forum section we have the first in a series of engaging articles written by Curtis Peebles in cooperation with NASA. I think you will find the piece simultaneously enjoyable and humbling.

In addition, Don McCauley and Gordon Cress, two long-time friends and SAFE Dinosaurs, complement the NASA paper with their own look at the escape industry over the last few decades. They were *there,* and their experiences and observations fit well into the aesthetic of the Forum section. For any of our readers into their forties, fifties, or sixties we perhaps knew the early pioneers in the rocket engine era; and I am sure many of you will remember the names and faces Curtis writes about—and many will have lived and worked in the areas Don and Gordon discuss in their editorial. It is my hope that the Forum portion of the journal will therefore provide some surprisingly personal material for the enjoyment of many.

Let me also briefly outline the coming year. Our process of peer review has been modified to an *optional* peer review process. This means that all submitted papers will be reviewed by those familiar with the area or topic and provide an unbiased recommendation to the Publications Team. Pending these reviews, the paper can be rejected, approved or approved with changes. In 2006 we processed 11 papers through the system, and have 7 more already planned for 2007. I would strongly urge you to consider submitting your own original works to the Association for possible inclusion in future journals.

In addition to Journal editing, the Publications Team assists in the efficient organization of the Symposium Technical Program, outlining sessions and formats, and coordinating all AV to ensure the attendees have a great show. Our 44th Annual SAFE Symposium will be held in Reno, NV. The Symposium provides an international marketplace for the exchange of technical information, product and service exhibitions, and showcases industry capabilities for meeting challenges in vehicular occupant protection and personnel-worn safety and life support equipment. The SAFE Symposium is attended by acquisition and technical leaders from worldwide industry, governmental, and military agencies. From this show, many of the potential publishers for the Journal can be identified.

Overall, it has been a great year for the Publications Team, and I look forward to the growth of the SAFE Journal and review process implementation. We appreciate all of your support and eagerly await the continued submittal of technical papers—works that further represent the rich, innovative heritage that is the basis for the SAFE Association we know today.

RESEARCH, DEVELOPMENT, TEST & EVALUATION SECTION

Degradation of Pilot Reach Under G

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ABSTRACT

A pilot's ability to perform arm reach in the cockpit can be compromised by high-sustained acceleration (G). This research provides performance test data on reach to aircraft controls under several levels of sustained acceleration, especially negative G. Currently, Government requirements documents and aircraft manufacturers use locked harnesses at 1 G to simulate reach to controls at > 1 G. This research was conducted to determine the effects of reduced reach capability on pilot accommodation levels.

BACKGROUND AND RELEVANCE

High-performance fighter and attack aircraft currently in the USAF inventory (F-16, F-15, A-10, and soon, the F/A-22) are capable of achieving and sustaining G levels that exceed human tolerance. Recently, several aircraft accidents have been attributed to pilots in adverse G conditions having difficulty reaching controls. This research evaluated reach problems during negative G and reach assumptions made by aircraft manufacturers during cockpit design.

METHODS

The experiment was conducted in the Dynamic Environment Simulator (DES), a man-rated centrifuge in the Air Force Research Laboratory at Wright-Patterson AFB OH (Fig 1).

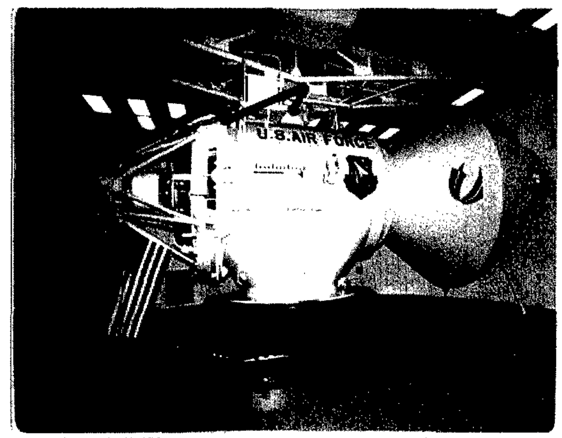

Figure 1. The Dynamic Environment Simulator centrifuge.

An approved ACES II facsimile seat was mounted in the cab of the DES. Two seat back conditions were tested, F-16 (30 deg) and F-15 (15 deg). Structures representative of aircraft switches were also installed in the cab (Fig 2).

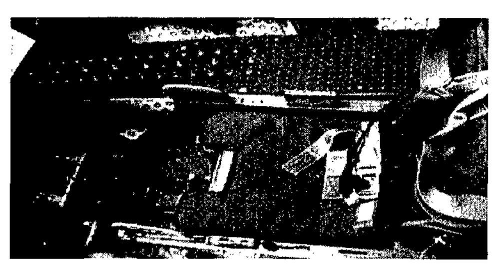

Figure 2. Top view of the ACES II-like ejection seat in the DES cab. The seated subject would be facing to the left. The switch panel is shown at the top, or on the right side of the seat.

These switches were used to evaluate reaches in three restraint harness conditions called "reach zones" as defined in Mil-Std 1333. Zone 1 reaches are attempted with a locked inertial reel and the pilot's shoulders must remain in contact with the seat. Emergency controls such as the ejection handles must be actuated in this restraint condition. Zone 2 reaches also are with locked reels, but the pilot is free to stretch as far as possible to actuate controls. Requirements documents typically include the primary flight controls as Zone 2 requirements. Zone 3 reaches are with unlocked reels and the pilot is permitted to lean forward to actuate all remaining controls in the cockpit. Listed below is an example from a previous USAF program.

Table 1. Example of USAF Reach Requirements

Required Controls Operable Under Zone 1 Conditions:

- All primary and secondary in-flight escape system controls, Inertial lock manual selector,Control stick, rudder pedals, and power control levers in neutral position

Required Controls Operable Under Zone 2 Conditions:

- Power control levers, full operational range
- Control stick, full operational range
- Trim override
- Rudder pedals, full operational range
- Emergency ground egress controls

Desired Controls Operable Under Zone 2 Conditions:

- Flaps
- Master caution cancel
- Nose gear steering engage and disable
- Toe brakes
- All power control lever (PCL) and hands on PCL and stick and throttle (HOTAS)
- Speed brake

SUBJECTS

The 17 subjects were all members of the Sustained Acceleration Panel, which is composed predominately of volunteer active duty Air Force members. These individuals qualify for the panel only after successfully completing an extensive medical evaluation and, in order to continue to participate, they must provide their ongoing informed consent. Simple anthropometric and strength measurements were made to rank order the subjects.

MEASUREMENTS

Baseline reach measurements at 1G were recorded for each subject. At each G level an exposure consisted of one Zone 2 reach (locked harness) to the switch row to determine the maximum forward reach possible, followed by a Zone 3 reach (unlocked harness with the subject leaning as far forward as possible) to the switch row. The switches were 2 inches apart. Both of these reaches were then repeated and averaged. The data reported are the differences between these two reaches. These reaches were performed with a locked restraint harness at - 1, +1, +2, +3 and +4 Gz. The same routine was then repeated with an unlocked harness. Prior to a G exposure the subject was instructed to initially place their hands in a stick and throttle position. They were then held at the particular G level until the switch was flipped or 10 seconds passed, whichever occurred first. As the subjects leaned forward to reach toward the controls, the effect of the positive G was to force their head into their lap. This made reaches difficult to accomplish. For that reason, subjects were allowed to "finger crawl" up the switch panel for support. Therefore, the time required to reach a control greatly increased.

EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

Each subject was measured for anthropometric dimensions and simple strength testing. This was done to allow us to classify each subject relative to the sample. Data analysis included simple reach differences over the sample and their possible correlation with size and strength. Subjects performed maximum reaches toward a set of toggle switches on the right side of the ACES II.

RESULTS

The results are presented in Figure 3. F-15 data are in the graph on the left, F-16 on the right. On the Y-axis we have reach differences in inches with the reel locked and then unlocked. The X-axis is the Gz level ranging from –1 to +4 Gz. The mean difference of reach – from 1 Gz – is shown below each G level. The numbers shown on the graph are the number of subjects with that particular reach difference. The line segments connect means from each G level. The F-15 subjects were able to reach 8 to 12 inches further at 1, 2, 3, and 4 Gz (unlocked reel) than they could at 1 Gz locked. F-16 subjects were able to reach 6 to 10 inches further at 1, 2, 3, and 4 Gz (unlocked reel) than they could at 1 Gz locked. F-15 subjects were only able to reach, on average, 0.6 inch further when unlocked at –1 Gz than at +1 Gz locked. F-16 subjects were able to reach, on average, 4 inches further when unlocked at –1 Gz than at +1 Gz locked. The –1Gz reaches were physically very difficult.

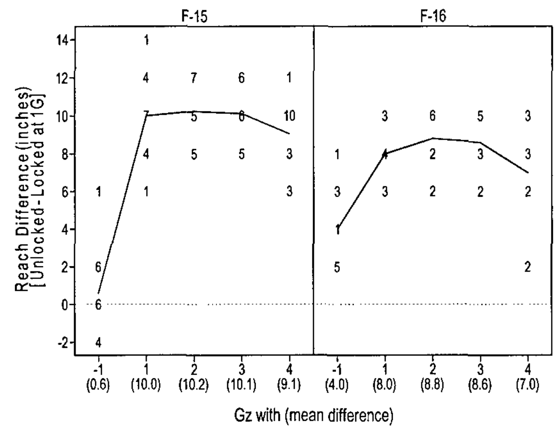

Figure 3. Reach as a Function of G in 15 and 30 Degree Seats

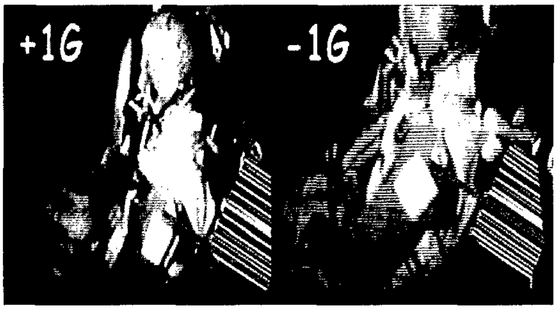

Figure 4. Shoulder Displacement from +1Gz to –1Gz

Also, as shown in Figure 4, when under negative G, our subjects averaged 3.8 inches of vertical shoulder displacement from the +1 Gz condition. In other words, the lap belt allowed them to "hang" nearly four inches out of the seat.

DISCUSSION

Quantifying arm reach in a cockpit becomes a multivariate body size question; that is, reach to a particular control is a function of shoulder height, shoulder width, and seat position (1,2). These factors, considered in total, are important because even though two pilots may have the same arm length, their other body measurements will most likely differ. While pilots do not typically lock their inertial reels while flying, locking the reels tests whether the pilot can control the aircraft during adverse G conditions or when there is an inadvertent or accidental restraint lock in flight. Typically, aircraft manufacturers assume the pilot must operate the inertial reel lock; emergency controls such as the ejection seat handles, and primary flight controls in this condition. Pilots who wear their harness loosely (in order to assist in "checking six"—meaning the ability to turn in their seats to look directly behind them for an adversary) can find themselves 'hanging' in the loosely fitting harness at the top of their canopy during a negative G maneuver and unable to reach these crucial controls.

The F-15 subjects were able to reach further down the switch panel than their F-16 counterparts because of the more vertical seat-back angle. The 15 deg seat back difference (15 vs. 30 deg) made it easier for the F-15 subjects to reach forward. The subjects were able to reach 6-12 inches further in the unlocked reel condition than in the locked condition for +1 through +4 Gz. For positive G the locked reel simulation of adverse G is not a good estimate for distance, at least up to 4 G, however, though not measured, the observed time necessary to reach these controls was dramatically increased under G > 1 than at +1Gz.

This part of the research may be repeated at a later date for G levels up to 9 G. There is a downward trend in the graph starting at 4 G and this may approach zero as G increases (Figure 3).

CONCLUSIONS

In this research we found pilot right-arm reach distance is unaffected by 2, 3, and 4 Gz, but the time required to reach the control is increased. However, during exposure to −1Gz, pilot arm reach is significantly reduced due to poor restraint by the lap belt. While the locked inertial reel rule-of-thumb to simulate high G effects in the cockpit appears to be inaccurate for positive G (at least up to + 4 Gz), the additional time requirements and the dramatic effect of negative G suggest that continued use of locked reels requirements is warranted for emergency controls that must be actuated very quickly.

ACKNOWLDEDGEMENTS

The authors wish to thank the Veridian Engineering support staff, which configured the DES cab and conducted the centrifuge set-up and operations. The volunteer subjects and the AFRL/HEPA medical staff are also acknowledged for their support in this research.

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Evaluation of Acceleration Response during AFRL $+G_z$ Vertical Deceleration Tower Tests

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ABSTRACT

An analysis and comparison of impact acceleration responses in male and female pilot subjects is presented. This study is motivated by the increasing number of gender-related laboratory tests to determine if males and females respond differently to the high impact accelerations simulating in-flight ejection from military aircraft. Acceleration response data are analyzed and compared using vertical drop tower tests from Study No. 199906 conducted by the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base, Ohio. Acceleration time histories at the seat pan, T1 (1st thoracic vertebra), head and chest, were recorded for +Z axis impact accelerations of 6, 8 and 10 G's. The results demonstrate that males and females respond similarly to ejection-like impacts. The greatest percent difference in peak acceleration response between male and female subjects in the 10 G test occurs in the chest at 9.2%, followed by the T1 and head at 8.1% and 4.8%, respectively. All differences have p-values of ≤ 0.05. With uncertainty, however, the difference between male and female values might not exceed 4% at any location. Smaller differences between genders are found in the time-of-peak ($\leq$ 2.5%). Minimal correlation is found between mass or sitting height with the magnitude of peak acceleration or time-of-peak. All correlations are $r \leq 0.26$. A stronger correlation of $r = 0.84$ is found between subject mass and sitting height for all subjects. This independent study of the AFRL data confirms many previous conclusions while establishing additional insights into this unique set of experimental data.

INTRODUCTION

Since the recent introduction of females into combat aircrew positions, a number of questions have arisen concerning the risk of spinal injury in females, especially during the initial stages of in-flight ejection when seat acceleration is highest. These concerns are valid since most impact tests and evaluations to determine risk of ejection injury were conducted for a 50th percentile of the male pilot population and a smaller range of pilot sizes. Not until the late 1990's did testing of females in ejection-like loads occur.

Engineers of the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base in Dayton, Ohio, are leading the investigation of female response to impact accelerations, especially through the many experiments and data collected at their vertical deceleration tower (VDT) facility. To date, experimental studies of ejection-like impacts have shown no significant differences in spinal response between male and female subjects. One of the first published studies Buhrman and Mosher (1999) evaluate male and female subjects exposed to vertical impact acceleration pulses. The magnitude and duration of the subjects' acceleration responses are measured and compared, and analytical techniques are used to compute the undamped natural frequency and damping ratio for each subject. The results demonstrate similar magnitude and duration of the chest acceleration response in males and females, with small differences in the undamped natural frequency as a function of subject weight.

Burhman and Wilson (2003) compare bone mineral density (BMD) and vertebral stress between male and female pilot subjects using Quantitative Computed Tomography (QCT). The results demonstrate no significant differences in either BMD or vertebral stress between males and females, but found that taller, lighter individuals of both genders experience slightly less stress than shorter, heavier individuals.

Siedlecki et.al. (2002) show strong correlations between various anthropometric measurements and vertebral body

size in male and females. Regression equations are established to provide estimates of vertebral body cross-sectional area to within 10% of measured values. These estimates are valuable as they can be used in conjunction with current biodynamic models to evaluate and minimize the risk of spinal injury in both males and females.

Morris and Popper (1999) report experimental measurements of bracing against non-vertical impact accelerations. An attempt is made to identify a correlation between gender, braceablity, static strength, anthropometric measurements, or combinations thereof. It is concluded that no useful correlations exist and that gender is not found to be a factor in predicting non-vertical impact accelerations.

Despite the work that has taken place in the last few years, experimental data from a number of vertical deceleration tower (VDT) tests conducted at the AFRL, demonstrate noticeable differences in upper body response among subjects. Whether these disparities are due to physio-logical size or gender differences has not yet been established. Data often shows peak accelerations and times-of-peak varying as much as 30% among individual subjects, giving credibility to the theory that significant differences do exist between genders. Furthermore, a comprehensive ejection injury database has not been compiled for females. Since females have an average 30% less body mass than males, a spine that is 10% shorter, a 25% reduction in vertebral cross sectional area and a 20% reduction in vertebral breaking threshold, it is imperative that further analysis is conducted to isolate spinal response difference between genders. If no significant difference exists, attention should be given to why this condition exists despite the obvious anatomical gender differences discussed earlier.

The objective of this study is to analyze live human response data from vertical impact accelerations of twenty male and twenty female subjects of various anthropometric dimensions, under identical initial conditions. The effects of subject gender and anthropometry on human response to impact and vertebral loading will also be investigated. The results might lead to the development of more robust biodynamic models that will be useful in predicting probability of injury to the female flying population during the early stages of in-flight ejection.

AFRL BIODYNAMICS DATABASE

Experimental data used in this study is taken, by permission, from the AFRL Biodynamics Database under Study No. 199906. Forty-five human subjects are voluntarily exposed to vertical acceleration pulses at presumed noninjurious levels using the AFRL Vertical Deceleration Tower (VDT). All subjects are members of the AFRL Impact Acceleration Panel and were medically qualified for VDT testing. The use of human volunteers in this experimental protocol was approved by the Wright Research Site Institutional Review Board (IRB) at Wright-Patterson AFB, Ohio.

Of the forty-five subjects tested, twenty males (n = 20) and twenty females (n = 20) of various sizes are chosen due to completeness of test data. The subjects are tested under identical conditions at 6, 8 and 10 G's. One test per subject is conducted at both 6 and 8 G's, respectively, while three tests per subject are conducted at 10 G's. The 10 G acceleration level tests are deemed more important as they are closest to the actual acceleration experienced by the body during in-flight ejection.

Sixty anthropometric measurements were taken on each subject. Of those, only four measurements proved to be of interest in this study: mass, sitting height, stature and age. These values can be found in Table 1. Subject demographics are consistent with the Air Force pilot population for allowable mass (AF standard is 46.8 to 105.2 kg), stature (AF standard is 162.6 to 195.6 cm) and age (AF male mean is 33.2 yrs, AF female mean is 29.2 yrs).

Table 1. Key anthropometric measurements (± σ) for the twenty male and twenty female subjects in this study.

Parameter	Males *n = 20*	Females *n = 20*	% Diff
Mass (kg)	86 ± 14	61 ± 8	-29.1
Probable Range	66 - 109	50 - 76	
Sitting Height (cm)	95 ± 4	86 ± 6	-9.5
Probable Range	88 - 105	64 – 91	
Stature (cm)	179 ± 7	164 ± 8	-8.4
Probable Range	168 - 193	146 - 175	
Age (yr)	33 ± 7	26 ± 6	-21.2
Probable Range	22 - 44	19 - 39	

A comprehensive list of details concerning the VDT apparatus and equipment used during the experiments are detailed in the AFRL Biodynamics Database. In general, the subjects were positioned in a generic seat mounted to the VDT carriage in the upright position, with the seat back perpendicular to the line of acceleration. The subjects were restrained with a double shoulder harness and lap belt and each subject wore a standard HGU-55/P flight helmet weighing 1.1 kg.

Figure 1 shows where four acceleration responses are measured: seat pan, T1 (1^{st} thoracic vertebra), head, and chest. The seat pan acceleration can be used as a basis for the input acceleration to the body. All accelerations are measured using a linear tri-axial accelerometer package at each location and data are collected at 1,000 samples/sec.

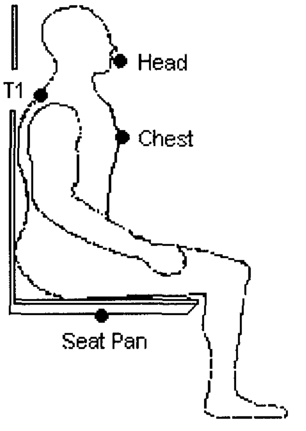

Figure 1. Locations of accelerometers commonly used in Air Force VDT tests (adapted from AFRL).

A typical acceleration response plot resulting from a VDT test is shown in Figure 2 and demonstrates accelerations in the four locations. The seat pan acceleration acts as the input and as expected, peaks at approximately 10 G. Each of the corresponding responses in the upper body exceeds the input acceleration, demonstrating the dynamic overshoot present in the human body. Of primary interest is the magnitude of peak acceleration and the time-of-peak acceleration. These parameters directly reflect the amount of displacement present at each of the locations in the upper body due to the forces of the impact. Excessive displacements cause spinal injury.

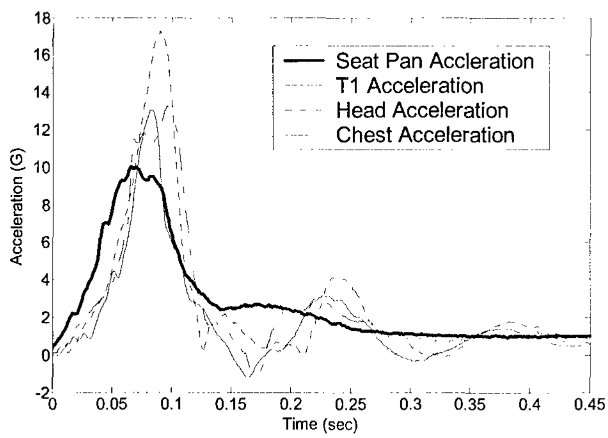

Figure 2. A typical acceleration response plot at 10 G showing accelerometer readings at the seat pan, T1, head and chest.

METHODOLOGY OF ANALYSIS

In order to characterize the acceleration data, box plots are performed on collected data for each accelerometer location and are reported in the Results. The plots show the center of each data set (median), where most data fall (1st and 3^{rd} quartiles), the spread of unquestionably "good" data, and possible outliers. The box plots also give good relative perspective of response from one acceleration level to another. Means and standard deviations are also calculated for acceleration peak magnitudes and times-of-peak for each subject at each accelerometer location. These data are displayed in table format for all VDT tests: 6, 8 and 10 G's. Percent differences between male and female results are also calculated and displayed in each table and displayed in bar graph form. Scatter plots, with their corresponding regression lines and Pearson product-moment coefficients (r) are used to provide statistical analysis of the 10 G response data as a function of mass and sitting height.

RESULTS

In order to ensure consistency in initial conditions among subject tests, a critical look at several parameters is first required. Table 2 details comparisons between average velocities, rise times and pulse widths of male and female subjects at different acceleration levels. The percent differences in all parameters are statistically insignificant, with the 8 G test velocities showing the greatest difference of 2.7%. This anomaly is likely due to experimental error in the velocity tachometer, as all other values in the 8 G test are very small.

Table 2. Average velocities, rise times and pulse durations ($\pm \sigma$) at the three acceleration levels for male and female subjects.

Measured Parameter		Males *n = 20*	Females *n = 20*	% Diff
Velocity (m/s)				
Test	*6 G*	6.2 ± 0.3	6.3 ± 0.4	1.6
	8 G	7.5 ± 0.7	7.3 ± 0.6	-2.7
	10 G	8.4 ± 0.5	8.3 ± 0.5	-1.2
Rise Time (ms)				
Test	*6 G*	91.8 ± 2.4	91.1 ± 2.7	-0.8
	8 G	81.5 ± 1.3	81.4 ± 1.3	-0.1
	10 G	74.6 ± 2.3	73.6 ± 2.5	-1.3
Pulse Duration (ms)				
Test	*6 G*	163.9 ± 2.8	163.3 ± 3.3	-0.4
	8 G	152.2 ± 1.7	151.8 ± 1.4	-0.3
	10 G	145.8 ± 2.3	145.0 ± 2.5	-0.6

Anthropometry

With respect to anthropometric measurements, one significant correlation was found between subject mass and sitting height. An r-value of 0.84 exists for both male and female data. When evaluated separately, r-values of male data were better correlated (r = 0.69) than female data (r = 0.52). This finding is similar to that of Buhrman and Mosher (1999).

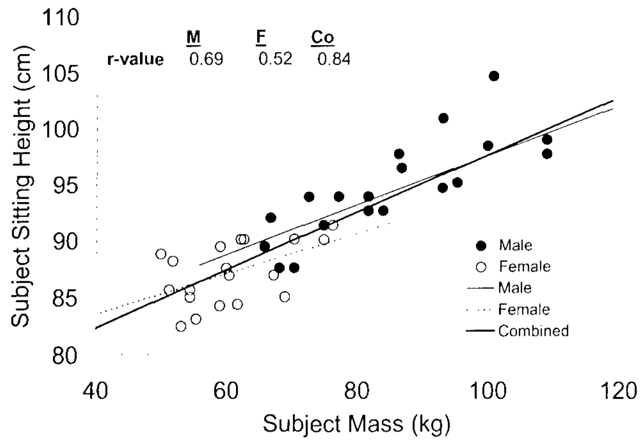

Figure 3. Sitting height vs. mass of all subjects (n = 40). Linear regression lines and Pearson's coefficients (r) are given.

Peak Acceleration

Based on the box plots presented in Figure 4, on the following page, a relative observation can be made in the variability among the data sets of the various locations. The figure displays peak accelerations for the 6, 8 and 10 G tests for 20 male and 20 female subjects. Table 3 details the data in numerical form. The measured seat pan accelerations have very little variability in peak acceleration when compared to measurements actually taken on the human body, as expected. Variations in the seat pan are minimized since the accelerometer is mounted onto the rigid seat/carriage assembly, and not on the viscoelastic body. Since the seat pan acceleration acts as an input acceleration to the human subject sitting atop the seat, the peak acceleration is shown to nearly equal the nominal acceleration of the test. Therefore, a 10 G VDT test has a seat pan acceleration of approximately 10 G. In a VDT test, this acceleration is controlled by adjusting the height from which the seat is dropped. The height is a function of subject mass. Based on the seat pan acceleration values in Table 3, it can be concluded that a negligible difference exists between male and female data at the seat pan.

As seat pan acceleration data contains the least amount of variability, the T1 data has the most. This is primarily due to the fact that the T1 accelerometer is difficult to affix to the upper back of the human subject. Variability inevitably mounts as the accelerometer's position on the upper back moves with respect to the body during testing. A further review of the data reveals that the peak acceleration at the T1 increases with increasing input acceleration. Variability in the data also increases from 6 to 10 G's. The greatest difference in peak T1 acceleration between male and female is in the 10 G test with a change of 8.1%. The T1 accelerations are also the largest of the four locations with values at or near 20 G.

Table 3. Peak accelerations data ($\pm \sigma$) of the three acceleration levels, for male and female subjects.

Measured Parameter	Males	Females	% Diff	p-value	N
Peak Seat Accel (G)					
6 G	5.97 ± 0.1	5.97 ± 0.1	0.0	NSD	20
8 G	8.01 ± 0.1	8.03 ± 0.1	0.3	0.02	20
10 G	10.0 ± 0.1	10.04 ± .1	0.4	≤ 0.01	60
Peak T1 (G)					
6 G	9.1 ± 2.2	9.3 ± 1.6	2.2	0.19	20
8 G	14.5 ± 2.0	13.8 ± 2.6	-4.8	0.14	20
10 G	20.0 ± 4.7	18.5 ± 2.5	-8.1	0.03	60
Peak Head (G)					
6 G	8.6 ± 1.3	8.5 ± 1.0	-1.2	NSD	20
8 G	11.3 ± 1.1	11.5 ± 1.1	2.0	0.47	20
10 G	13.8 ± 1.5	14.5 ± 1.7	4.8	0.01	60
Peak Chest (G)					
6 G	8.2 ± 1.4	7.6 ± 0.9	-7.6	0.29	20
8 G	11.4 ± 1.2	10.8 ± 1.2	-5.6	0.05	20
10 G	14.3 ± 2.2	13.1 ± 1.3	-9.2	≤ 0.01	60

Head acceleration response data have noticeably less variability than the T1 data. Peak head acceleration, in Figure 4, rises uniformly as the input acceleration increases. Head accelerations experience the largest difference between male and female data in the 10 G test at 4.8%. Differences in the 6 and 8 G tests are minimal. With little variability, the chest acceleration data shows a similar incremental increase in peak response from 6 to 10 G, as the head accelerations. Percent change between male and female data is more significant in the chest acceleration measurements with differences of -7.6%, -10.8% and –14.3% for the 6, 8 and 10 G tests, respectively.

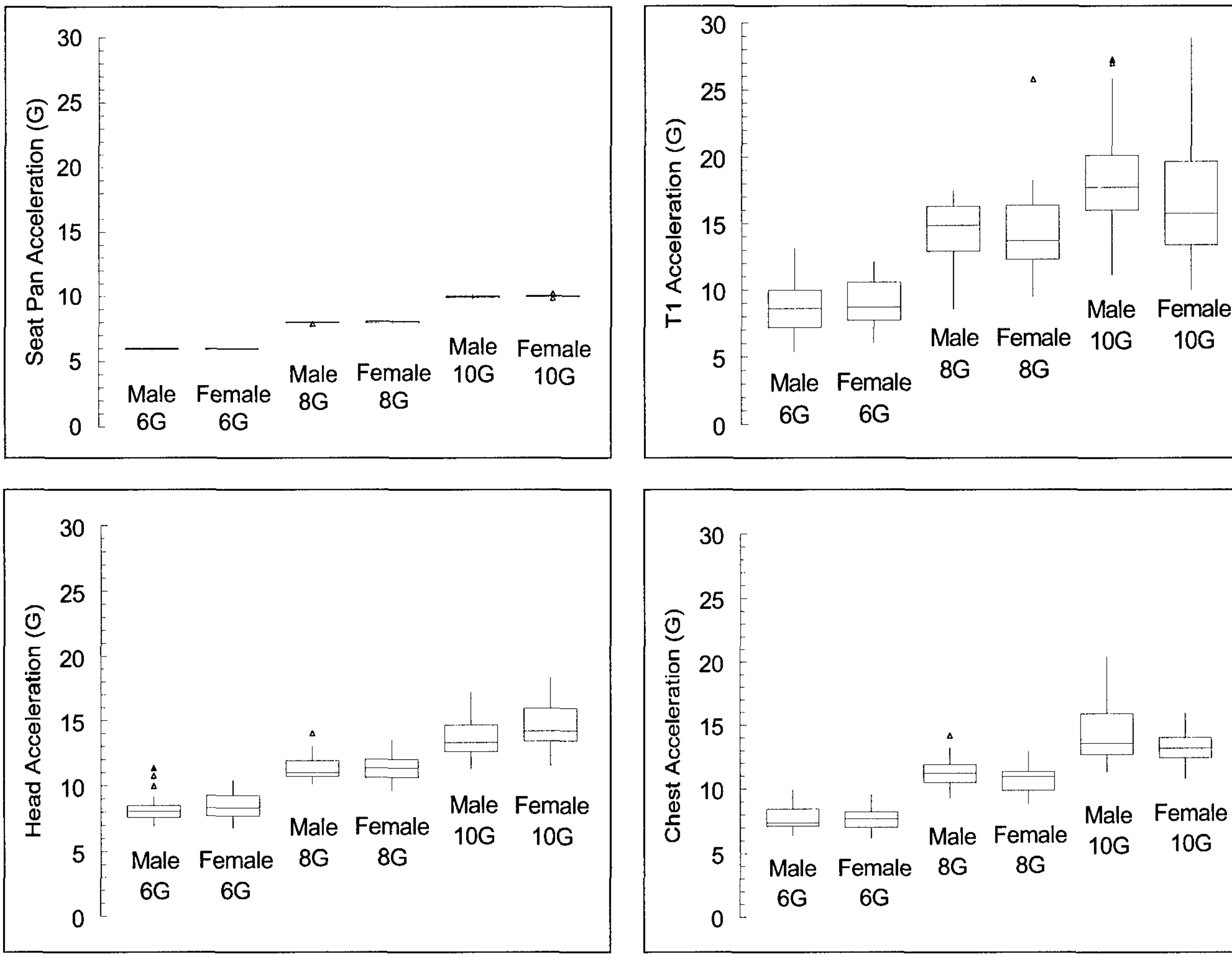

Figure 4. Peak acceleration data for all accelerometer locations at 6, 8 and 10 G, for male (n = 20) and female (n = 20) subjects. Each data set contains 20 tests, one per subject.

Several other key observations can be made in the data represented in Figure 4. First, acceleration response does not linearly increase with increasing input acceleration. This is demonstrated in Figure 5 where the acceleration difference between the nominal G load and the corresponding response is plotted for the three body locations. Two G increments in input do not associate with two G increments in the response. Moreover, the response does not increase in even increments but more in an exponential manner. Tests exceeding 10 G would give higher confidence in this observation. Another trend lies in the percent differences of the peak accelerations, as seen in Figure 6. The greatest percent differences are seen in the higher G tests. The difference between male and female seems to grow with increasing G load. Again, more tests of higher G loads would be helpful.

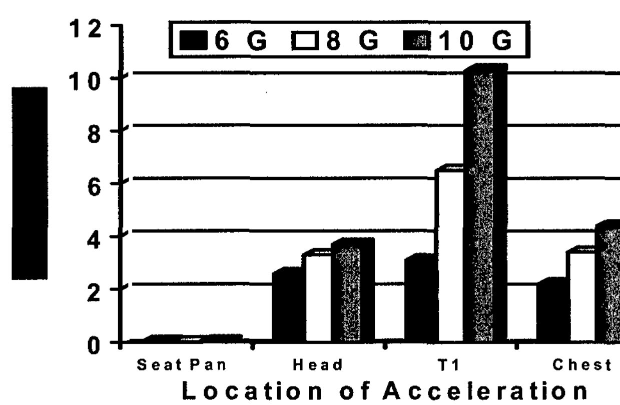

Figure 5. Difference between nominal G value and the measured G value at each accelerometer location, for male subjects. Female subjects give similar trends.

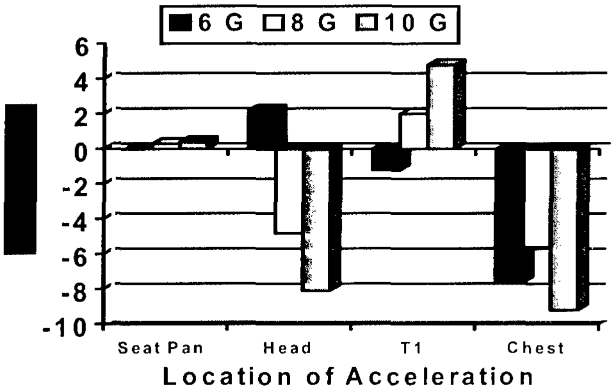

Figure 6. Percent difference between male and female peak accelerations for each accelerometer location.

Time-of-Peak Acceleration

In Figure 8 on the following page, time-of-peak acceleration is displayed for the peak acceleration data of Figure 4. Table 4 gives the data in numerical format. In general, the times-of-peak decrease as the input acceleration increases, since the boxes step down in time from 6 to 10 G's. This is expected since increasing input acceleration decreases rise time, giving less time for the seat-occupant to react to the impact. One interesting anomaly occurs in the 6 G data due to a delay in the time-of-peak. This is a result of a flattened seat pan acceleration curve, shown in Figure 7. Seat pan acceleration pulses of higher G's usually peak immediately after rises from the initial 0 G state. The 6 G pulse hesitates in its peak time, thereby driving the 6 G test median values of time-of-peak at least 10 ms later than expected. This hesitation is a function of the shape of plunger used to create the impact, as well as the amount of acceleration imparted on the seat-occupant.

Variability in the times-of-peak is similar to that in the peak accelerations. Overall, the seat pan has the smallest variation with only the female 6 G test differing significantly from the other data sets. This is likely due to the 6 G test anomaly already discussed. Concerning T1 times-of-peak, a 5 ms decrease for each additional 2 G's of input acceleration is observed. The greatest percent change between genders is 7.7% in the 8 G test. The differences in the other tests are negligible.

The times-of-peak in the head data also decrease with increasing acceleration. Male and female results are very similar with all time-of-peak differences less than 3.6%.

The chest data is similar with relatively small differences in time-of-peak response between male and female subjects. The greatest percent change between genders is 4.1% in the 10 G test. In general, time-of-peak in the chest decreases as the input acceleration increases.

Table 4. Time-of-peak data (± σ) at the three acceleration levels for male and female subjects.

Measured Parameter	Males	Females	% Diff	p-value	n
Seat -Time of Peak (ms)					
6 G	92.9 ± 14.2	94.6 ± 13.1	1.8	NSD	20
8 G	77.4 ± 10.1	73.9 ± 3.7	-4.5	0.02	20
10 G	66.6 ± 1.3	66.7 ± 1.4	0.2	≤ 0.01	60
T1-Time of Peak (ms)					
6 G	82.6 ± 16.2	83.5 ± 10.8	1.1	0.29	20
8 G	74.2 ± 11.3	79.9 ± 12.1	7.7	0.05	20
10 G	73.4 ± 11.3	75.1 ± 14.0	2.3	≤ 0.01	60
Head-Time of Peak (ms)					
6 G	92.1 ± 10.6	91.6 ± 4.3	-0.5	NSD	20
8 G	80.6 ± 7.7	83.5 ± 4.1	3.6	0.14	20
10 G	76.1 ± 7.1	77.1 ± 4.1	1.3	≤ 0.02	60
Chest-Time of Peak (ms)					
6 G	96.3 ± 6.4	97.1 ± 6.4	.8	NSD	20
8 G	85.8 ± 7.1	88.6 ± 6.2	3.2	0.17	20
10 G	81.2 ± 6.9	84.7 ± 6.7	4.1	0.01	60

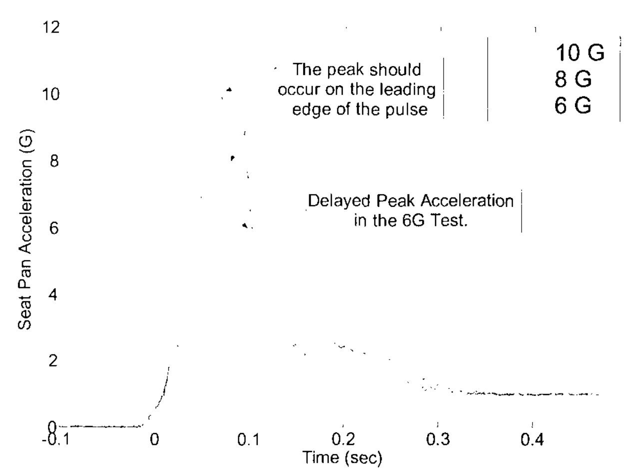

Figure 7. A demonstration of the delayed time-of-peak in the seat pan acceleration response curve for a 6 G test. The 8 and 10 G tests show an ideal peak on the leading edge of the pulse.

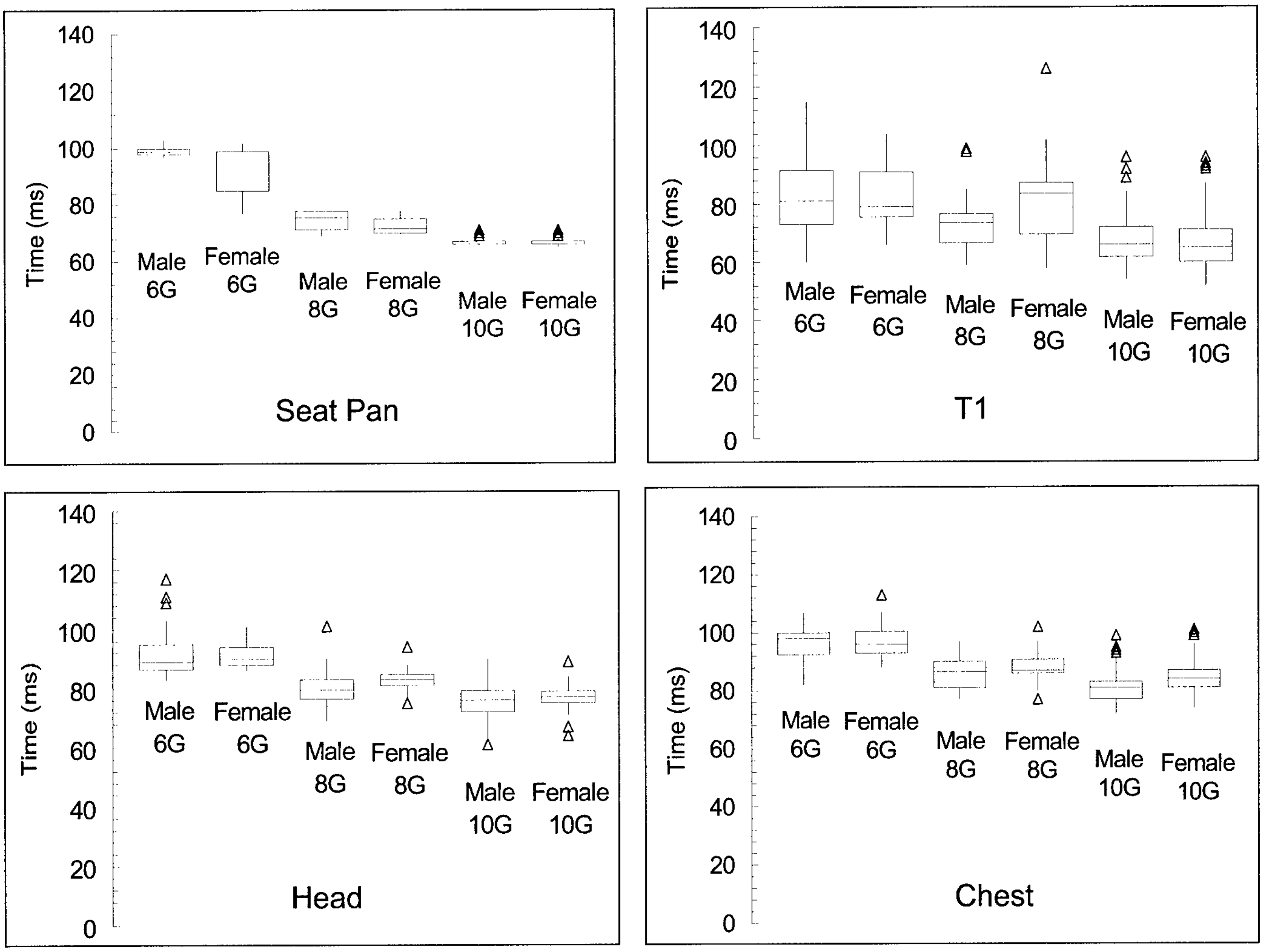

Figure 8. Time-of-peak data for all accelerometer locations at 6, 8 and 10 G for male (n = 20) and female (n = 20) subjects. Each data set contains 20 tests, one per subject.

Just as the input acceleration and corresponding peak acceleration responses correlate nonlinearly, so do the times of peak from one G load to another. Figure 9 illustrates the time-of-peak differences between 6, 8 and 10 G's. The difference in times decreases rapidly with higher G loads. The greatest difference is experienced in the head with time values changing from 11.5 to 4.5 ms, from 6 to 10 G. The smallest difference is found in the rigid seat pan.

Figure 10 displays the percent differences between genders at the four locations of measurement. Most differences are insignificant, with the largest found in the T1 at 7.7%. As in the peak acceleration data, the time-of-peak differences have standard deviations between 30% and 75% in the data sets. Therefore, no significant differences are seen between male and female response.

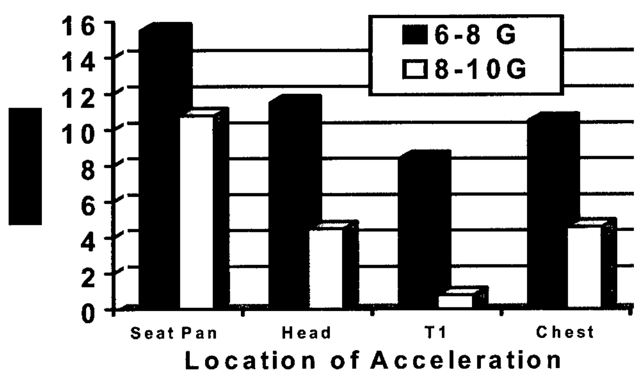

Figure 9. Difference of time-of-peak between the 6 and 8 G tests and the 8 and 10 G tests, at each accelerometer location, for the male subject. Female subjects give similar trends.

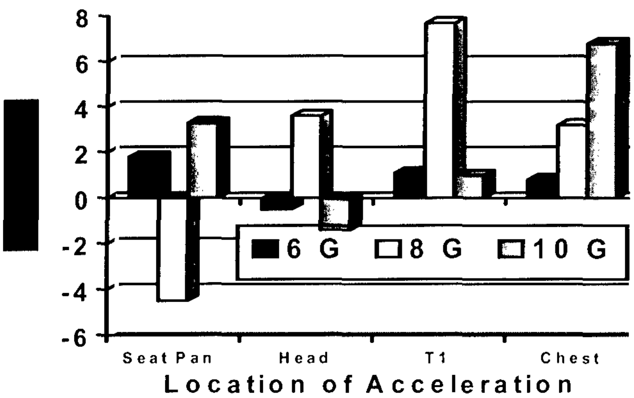

Figure 10. Percent difference between male and female times-of-peak for each accelerometer location.

Composite 10G Tests

A more thorough analysis is conducted for the 10 G VDT test data. Since three different 10 G tests were carried out for each subject, a total of 120 tests are available. Subjects were tested only once for the 6 and 8 G tests. More tests were conducted at the 10 G level since it closely mimics the acceleration experienced during an actually aircraft ejection. However, the acceleration level is still at a level that is considered to be non-injurious.

Figure 11 illustrates the composite 10 G data sets in the various locations of acceleration measurements. The locations are arranged in the chronological order in which they peak. The seat pan, acting as the input acceleration to the body, is first while the chest acceleration is fourth as it peaks last. The first observation is in the variability of the data. The seat pan has relatively no variability while the T1 data varies most, as seen in the comparison of the multi-G tests earlier. Head and chest acceleration vary by a nearly equal amount. Tables 3 and 4 give numerical representation of this data. As explained earlier, the T1 data varies greatly due to the difficulty in properly securing the accelerometer to the human upper back.

In Figure 12, time-of-peak measurements are characterized for the 120 data sets of the 10 G test. The most significant trend is the order of peaking in the various locations of the acceleration measurements. Table 4 also details this phenomenon. First to peak is the seat pan acceleration, followed by the T1, head and then chest. Since the thoracic spinal region and the chest are in the same area vertically, it is expected that the two would have similar peaking times. The delay in the chest may be due to the elastic properties of the viscera mass inside the thoracic cavity.

The percent difference (absolute) between males and females of the 120 data sets of 10 G tests is shown in Figure 13, with uncertainty. Figure 13 compares peak acceleration differences, with no difference higher than 10%. When taking uncertainty into account, the actual difference between male and female peak acceleration might not exceed 4% in any location.

Figure 13 also compares time-of-peak differences, with no difference higher than 4%. Since the differences are small and the uncertainties are relatively large, little difference is found between male and female time-of-peak acceleration. Error-adjusted differences do not exceed 2.5% in any location.

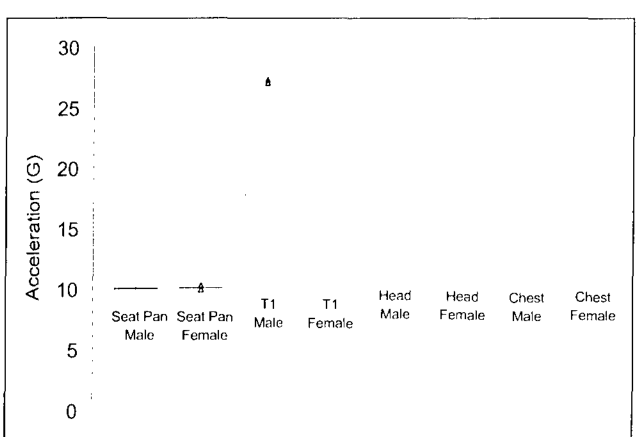

Figure 11. Peak acceleration data of the 120 data sets of 10 G tests for male (n = 20) and female (n = 20) subjects.

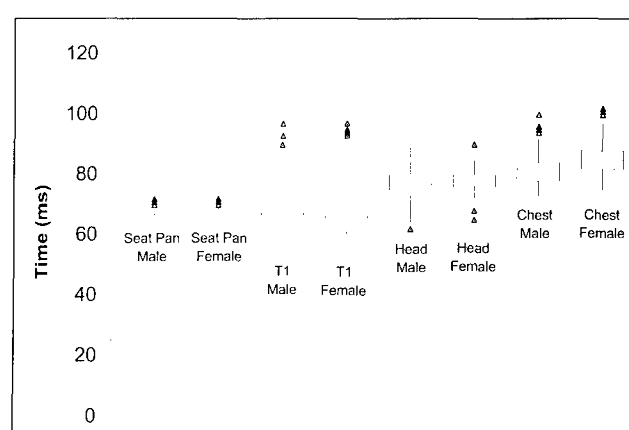

Figure 12. Time-of-peak data of the 120 data sets of 10 G tests for male (n = 20) and female (n = 20) subject

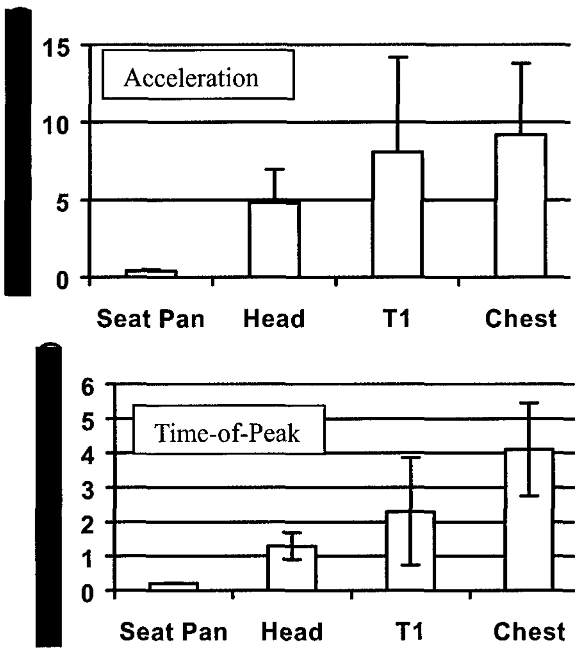

Figure 13. Percent difference in peak acceleration and time-of-peak for 120 data sets at 10 G, for male (n = 20) and female (n = 20) subjects. The average difference and corresponding uncertainty are plotted for each location.

The 10 G acceleration data has also been correlated with two important anthropometric parameters, mass and sitting height. Scatter plots of peak accelerations at each of the four accelerometer locations, with respect to the mass and sitting height, are shown in Figures 14-17 (pp. 11-12), for each of the subject tested. Three points per subject in each plot represent the values of peak acceleration or time-of-peak in three different 10 G tests. Correlations are sought between the anthropometric parameters and the respective peak acceleration and time-of-peak for both, male and female subjects, and as a collective group. Table 5 is a collection of r-values gathered from the scatter plots in Figures 14 and 15. No significant correlation are made between subject mass and peak acceleration or mass and time-of-peak. The best correlation is in the seat pan acceleration (r = -0.46).

Sitting height is another important parameter as it is closely related to spinal length. Table 6 shows the r-values gathered from the scatter plots in Figures 14 and 15. As with subject mass, however, no significant correlations are found between sitting height and peak acceleration or sitting height and time-of-peak. The best correlation is, again, in the seat pan acceleration (r = 0.57).

Table 5. Correlation coefficients for scatter plots in Figures 14 and 15, relating subject mass to peak acceleration and time of peak.

Measured Parameter	Males *n = 20*	Females *n = 20*	Combined *n = 40*
r			
Peak G-Seat	-0.42	-0.41	-0.46
Peak G-T1	-0.01	0.19	0.16
Peak G-Head	0.02	-0.21	-0.20
Peak G-Chest	-0.06	-0.10	0.21
Time of Peak-Seat	0.08	0.04	0.03
Time of Peak-T1	-0.02	0.08	-0.04
Time of Peak-Head	0.12	0.20	0.01
Time of Peak-Chest	0.42	-0.14	-0.07

Table 6. Correlation coefficients for scatter plots in Figures 16 and 17, relating subject sitting height to peak acceleration and time of peak.

Measured Parameter	Males *n = 20*	Females *n = 20*	Combined *n = 40*
r			
Peak G-Seat	0.24	0.05	0.57
Peak G-T1	-0.11	-0.08	0.03
Peak G-Head	-0.15	0.24	0.08
Peak G-Chest	-0.26	-0.07	0.10
Time of Peak-Seat	0.04	0.15	0.09
Time of Peak-T1	0.003	0.003	-0.04
Time of Peak-Head	-0.06	0.10	0.05
Time of Peak-Chest	0.19	0.13	-0.05

CONCLUSIONS

An analysis of laboratory data from vertical deceleration tower tests is presented in this study. Specifically, male and female spinal responses to aircraft ejection-like accelerations are compared. In general, it is concluded that male and female spinal response is remarkably similar in vertical impacts. The reason for this similarity, despite their anatomical differences, will be investigated in a future study. The following, specific conclusions can be drawn from this experimental data analysis:

1. As input acceleration increases from 6 to 10 G, (a) peak acceleration response increases nonlinearly in each region and (b) time-to-peak decreases nonlinearly in each region.
2. Time-of-peak is observed to occur in the following specific order: seat pan, T1, head and then chest. This order occurs regardless of the magnitude of input acceleration.

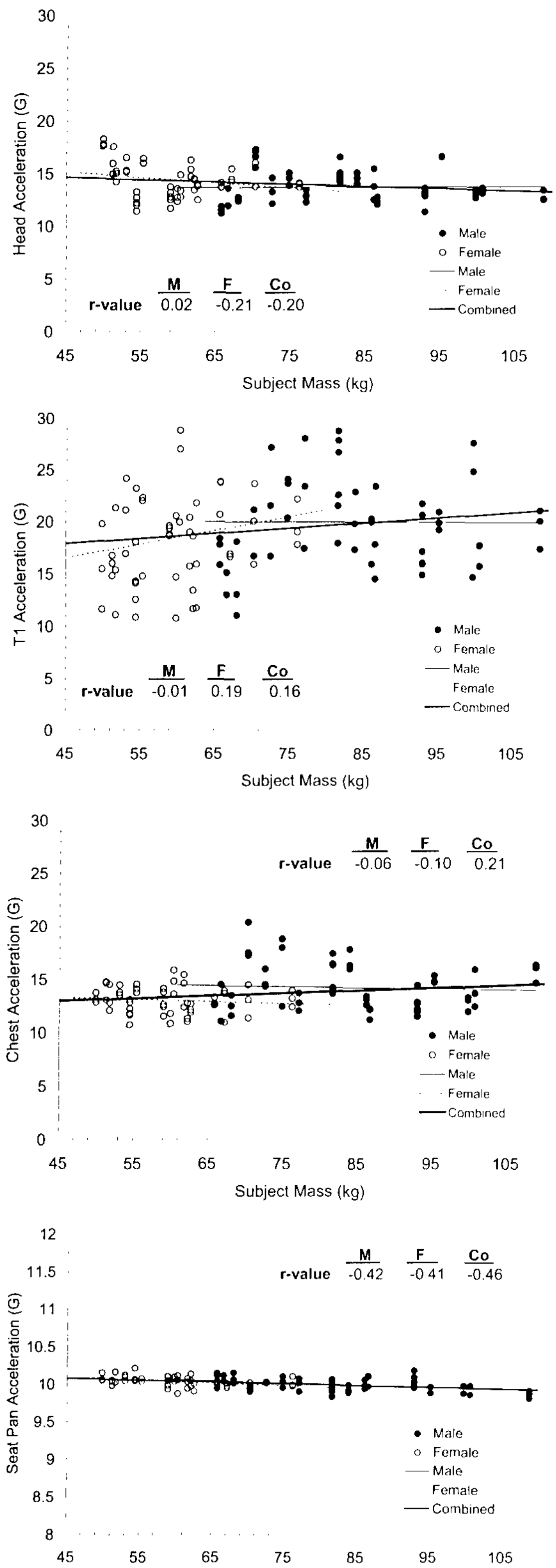

Figure 14. Peak acceleration data for 120 VDT tests at 10 G, with respect to subject mass for male (n = 20) and female (n = 20) subjects.

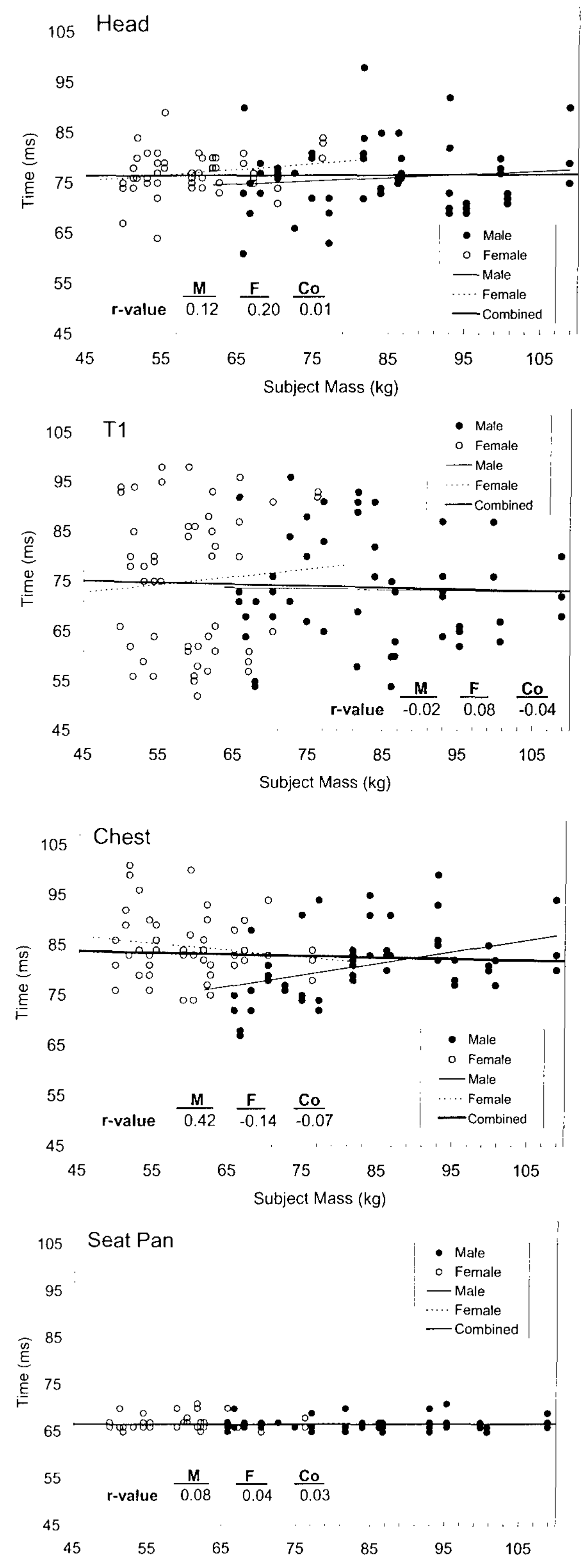

Figure 15. Time-of-peak acceleration data for 120 VDT tests at 10 G, with respect to mass height for male (n = 20) and female (n = 20) subjects.

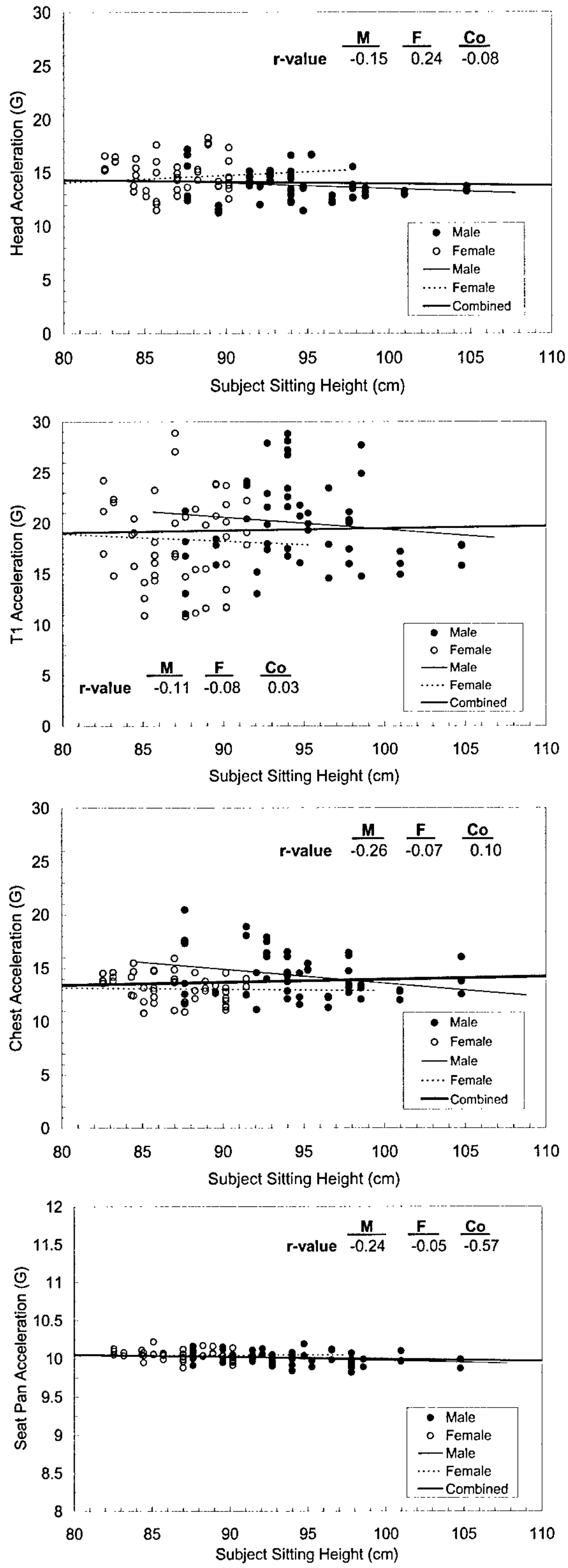

Figure 16. Peak acceleration data for 120 VDT tests at 10 G, with respect to subject sitting height for male (n = 20) and female (n = 20) subjects..

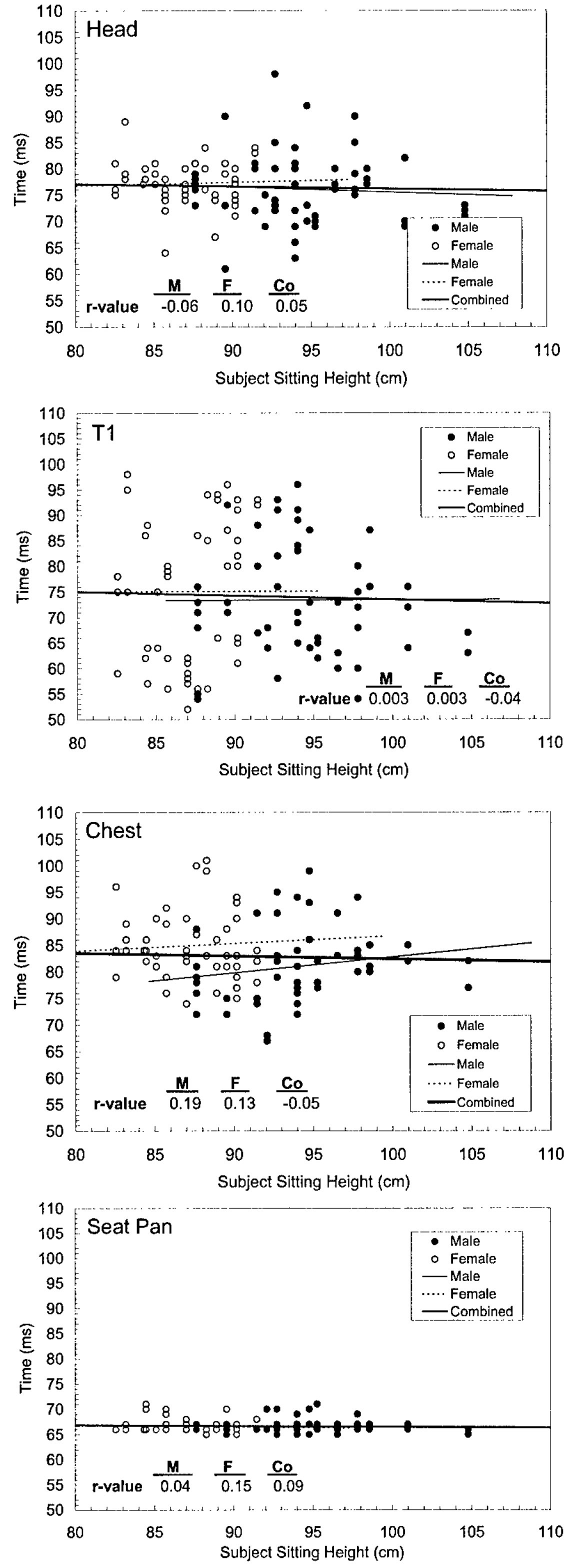

Figure 17. Time-of-peak acceleration data for 120 VDT tests at 10 G, with respect to subject sitting height for male (n = 20) and female (n = 20) subjects.

3. As input acceleration increases from 6 to 10 G, (a) peak acceleration response increases nonlinearly in each region and (b) time-to-peak decreases nonlinearly in each region.
4. Time-of-peak is observed to occur in the following specific order: seat pan, T1, head and then chest. This order occurs regardless of the magnitude of input acceleration.
5. A significant correlation ($r = 0.84$) was found between subject mass and sitting height.
6. Weak to no correlations are found between subject sitting height and peak acceleration response or sitting height and time-of-peak for each of three subject groups: male, female and combined.
7. Weak to no correlations are found between subject mass and peak acceleration response or mass and time-of-peak, for each of three subject groups: male, female and combined.
8. Among 120 VDT tests at 10 G, the greatest percent difference in peak acceleration between male and female subjects is in the chest at 9.2%, followed by the T1 and head at 8.1% and 4.8%, respectively. With uncertainty, however, the difference between male and female values might be less than 4% at any location. Seat pan acceleration difference was negligible at 0.4%. Even smaller differences between genders are found in the times-of-peak (≤ 2.5%).
9. Although males and females have similar spinal responses at equal laboratory G-loads, lower-mass-females will still experience more G-load in an actual ejection, based on their typical lower mass alone. This factor must be taken into account when calculating probability of spinal injury among genders.

ACKNOWLEDGMENTS

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BIOGRAPHIES

David B. Hamlin is originally from Tyler, Texas. After completing a B.S. inMechanical Engineering at the University of Colorado-Boulder, he was commissioned as a Surface Line Officer in the U.S. Navy. After serving on a destroyer and aircraft carrier, he completed a 3-year shore tour in the Joint Information Operations Center (JIOC) at Kelly Air Force Base, San Antonio, Texas. In January of 2000, he entered the Graduate School of The University of Texas at San Antonio to pursue a Master of Science degree in Mechanical Engineering. He has since left active duty military in order to join the civilian sector as a professional engineer.

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FORUM SECTION

First Hand Witnesses of Sled Testing Over the Past Forty Years

Gordon Cress and Don McCauley

This editorial offers some insight into the growth of the sled testing industry from a couple of dinosaurs of the SAFE Association. In this most technologically advancing world we thought it might be a good thing to review what we have seen during our careers and where this aspect of the test community may be headed in the next decade or so. The US aerospace industry has been rocketing sleds down tracks from Lakehurst N.J. in the east, to Hurricane Mesa and Holloman AFB, and Edwards AFB and China Lake in the west for over sixty years. These tracks have provided fundamental insight into human tolerance, weaponry, and escape system performance not possible elsewhere. Unfortunately, many of these facilities are no longer operational, or are in danger of closure.

PR & F SNORT Sled Tracks. Photo US Navy

Many of us at SAFE have been involved personally with these facilities and their programs. Tests dealing with escape systems constitute only one part of track operations, but are the aspect with which the authors are acquainted. These tests were the pivotal proof of cockpit, canopy and canopy jettison systems, sequencing systems, ejection seat and escape path clearance designs intended for the protection of aircrew. Before a system was entered into service, it had to pass a rigorous series of 22 successively successful track tests. The authors were privileged to have been a part of many of the programs for researching, validating and qualifying escape and recovery systems. Some of these programs included the Gemini Spacecraft, the F-111, the F-15, F-18, F-105, the F-106, the T-38, the T-46A, the YF-22 and the F-22A for example.

Planning, preparation for, manning and the execution of these test programs has remained essentially the same throughout our lifetimes, while track operations and the data acquisition systems have matured significantly. In the beginning, it was common for the manufacturer's team to go onto the track, set or check camera settings, the placement of screen boxes, check the instrumentation and ballistics, and anything else associated with the test.

The track facilities have progressed to the point where their personnel are professional and expert at these tasks, and control all aspects of track operation. The contractor/manufacturer merely states his needs and objectives through a test plan/operations document, prepares his test article, and the track personnel do the rest. The need will always exist for facility/contractor interface, a test plan and procedure, and test item preparation via a checklist, and a post-test evaluation procedure.

In our day, instrumentation packages were carried on-board the sled as well as in the chest

cavity of the test dummy. These provided data on sled acceleration, events such as system initiation, seat/canopy first motion, and seat distance vs. time up the rails; information that was not gathered during the flight of the seat: The early test dummy instrumentation packages commonly consisted of 8 to 12 channels of chest-mounted temperamental analog telemetry. The dummies (or manikins) were simple steel skeletons covered with rubber and had limited articulation. Available sizes were generally limited to five and ninety-five percentiles of the male flying population. Dummies were fitted with a chest cavity to accommodate the telemetry system and an antenna on the head under the helmet. We all prayed and hoped the antenna would not be blocked from the recording station as the dummy flew through the air during a test. The basic test data recorded during those early days consisted chiefly of tri-axial accelerations, rotation rates, one or two forces, and a few events. Batteries were wet cell types and the test dummies had to be kept generally in an upright position to reduce the chance of battery acid leakage.

As instrumentation came into the digital age and dummies became quite sophisticated, electronics technology came on-board and these systems gained more and more capability. The test team became heavy in personnel versed in electronics and data reduction. Those early data recording systems are a far cry from the sophisticated wireless, real time, and self-contained multi-channel systems now being used. Dummies as human analogues are coming on line that seem to feel and act nearly identically to humans.

Today's tests result in information on accelerations, rotations and a wide variety of forces and stresses applied to the test occupant and limbs from catapult ignition to touchdown. The test engineers have a much greater selection of manikin sizes available including the lighter weight representatives of the female flying population. More than 50 channels of information taken at thousands of samples per second may be obtained in any one test. Data from tests interact with computer models that predict human response to the test conditions with high accuracy. The link between data acquisition and the human response models is improving seemingly almost by the month. Some engineers are coming to feel that these sophisticated computer modeling systems are nearly as accurate as real test data and may have more application in that sled tests are limited to ground altitude and straight and level flight, whereas the computer analogs can simulate more closely the actual flight conditions. Sled and in-flight ejection tests are becoming of use more as a validation of the computer model rather as an end unto itself.

Photographic instrumentation was used to provide a visual record of the test and trajectory data. Photo instrumentation generally fell into four broad categories; tracking, sled-borne, fixed and trajectory. The tracking coverage ranged in camera speeds from 24 fps (nominal) to 400 frames per second and would provide a visual record of the test for analysis and evaluation of the system's performance. The tracking cameras and their operators were usually positioned along the track and anywhere from 500 to 1500 feet away from the track centerline. Each tracker was assigned a seat or dummy to concentrate on. However, the quality of the coverage depended on lens size and the experience and talent of the camera operator in those early days: - sometimes perhaps it also may have depended on what the operator did the night before ... It wasn't all that unusual at film reviews to see the escape system exit the vehicle, then lots of blue sky, and finally see the test dummy under a parachute just about to touchdown. And THAT was sometimes seen after the cameraman searched the sky for what seemed like an endless time.

Current systems use sophisticated laser technology and automated tracking systems and so have much improved the coverage, and in turn the engineers' ability to analyze the system functions. High resolution video has eliminated waiting for hours or days to see the coverage. Radar guided cameras currently used at NASA can track flight test vehicles well beyond visual range - almost as though one is watching a show on TV.

Sled-borne cameras placed inside the cockpit and outside the fuselage, provided close up system performance coverage. Internal cameras were used at times to record the seat movement up the rails and as backup instrumentation. Outside cameras using periscope lenses or boom-mounted cameras, provided detail coverage of canopy jettison, canopy hinge action and/or relative close-ups of the system as it cleared the vehicle. These cameras could focus in on specific areas and components and document response to windblast in intricate detail. Fixed still image cameras were located along trackside to record close-ups of canopy jettison and escape system egress. The quality of data from these cameras likewise ranged from limited to very valuable. It was often an educated guess as to where to locate these cameras, and just when to trigger them. At times these photos were spectacular and decorate the walls of track offices and private albums. The misses are unseen.

Trajectories of the seats and dummies, and sometimes of the canopies, were determined in three axes by data obtained from the fixed trajectory metric cameras using triangulation calculations. This is now an automated process. Finally, there was documentary coverage used to record mundane test preparations, test article installation into the sled test vehicle and post-test results.

The track facilities provide the propulsion for the sled. Even before our time, sleds were often constructed in one piece. Propulsion was mounted on the same frame as the test vehicle. The propelling rocketry was usually taken from expired military solid rocket devices of various sorts. There were times when the aged propellant was cracked and an explosion would result. More than once we watched as rockets soared overhead and end over end across the sands. We learned to separate the pusher from the test vehicle: it saved so much repair work! Some test programs have used liquid propellant rockets, but the majority used the easier to handle solid motors. The test vehicles ranged from salvaged fuselages modified for track testing to sophisticated specially designed and manufactured vehicles.

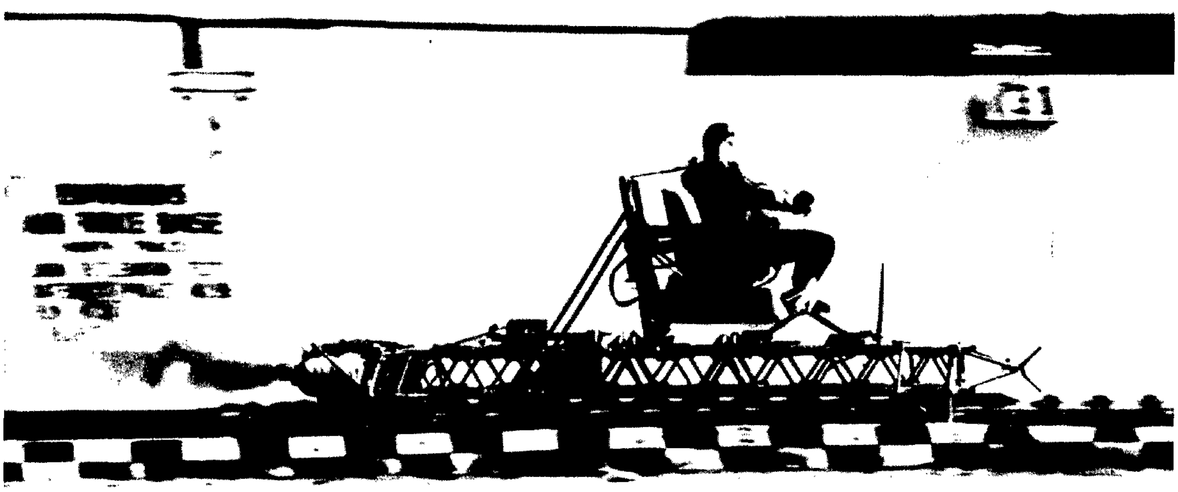
The early F-106 and F-105 programs are examples of the former while the F-22 program is an example of the latter. Today, there are only about three facilities available in the U.S. for dynamic ground testing of escape systems: government facilities at Holloman AFB in New Mexico and China Lake in California, and a privately owned Goodrich facility at Hurricane Mesa in Utah. In the last issue of this Journal this facility and its rich history was presented (Vol 33:1, 2005). Martin-Baker operates its own private facility in Northern Ireland.

As budgets remain depressed year after year, and under the lure of advancing human analog computer systems, the sled test will increasingly come under scrutiny as the primary means for flight certification and safety analysis. Some say they are too expensive. Some say the advances in computer control, dynamic high speed biomodels and trajectory analysis will eclipse the "old fashioned" sled test. For those of us that have seen the evolution, perhaps even participated in it, that "have been there" and are now fading away into retirement, we offer a simple word of caution.

Until we reach the point where all human operators of military tactical aircraft fly RPV's from easy chairs, there can be nothing more important than validating the dynamics of escape path clearance, learning, demonstrating and qualifying system performance through firsthand observation with sights, sounds and smells i.e. TESTS.

There is no substitute to getting up before dawn, freezing in the desert wind while the instrumentation folks go through their endless checks and tests, and watching those pusher rockets go off and seeing the parachutes in the distance – sometimes. Because hardware has a way of surprising you!

The legacy we leave to the new generation is to embrace the new, but remember the past. Feel the test, AND hear the results of the computer analyses. It is only through such experiences one can truly tell a pilot, "That system is safe. You can bet your life on it!"



Lt. Col. John Stapp on the rocket sled at Edwards Air Force Base.

Then and Now: Flight Research in the Second Half of the 20th Century

Curtis Peebles

On a morning in the first decade of the 21st century, a research aircraft and its chase planes wait at the end of the runway. Once everything is ready, they take off and climb into the clear blue sky. The research pilot then begins the first test point as the chase planes and ground controllers keep watch. The carefully choreographed flight plan is carried out at the planned speeds, altitudes, dynamic pressures, angles of attack and sideslip. The successful flight is the result of more than 50 years of advances in flight safety. And "flight safety" means not only survival equipment, but also flight planning, test procedures, simulations and a vast database of aerodynamic knowledge and experience. When the mission is over, the airplanes landed, and post-flight debrief completed, the research pilots, engineers and support personnel leave the NASA Dryden Flight Research Center, located on Edwards Air Force Base, California, by driving down Lilly Avenue.

Named for Howard Lilly, the first NACA research pilot killed in the line of duty, it is a reminder both of how much has been learned and the price paid for it. Today, few people remain who experienced that time, when the facility was limited to a single hangar with an attached lean-to for office space and a few makeshift dorms as housing. This was a time when a trip to Los Angeles required a long bus ride on winding two-lane mountain roads. Most important of all, it was a time when the pilots and crewmen were flying into the unknown.

The two decades following the end of World War II saw a revolution in aviation technology. Every aspect of aviation design and technology would change during this period. Pilots found themselves flying, on a daily basis, at speeds two or three times faster than they had during the war. The development of new aircraft, driven by Cold War rivalry and improvements in aircraft performance, came at a rapid pace. An environment characterized by rapidly changing technology, ever-greater speeds and altitudes and aerodynamic and engineering unknowns put test and research pilots into situations for which they were not prepared.

The result was a loss rate that today would be entirely unacceptable. Between 1947 and 1967, spanning the first two decades of supersonic flight, a total of 107 pilots, aircrew and passengers were lost in crashes. The losses came in 69 accidents, which included those during research missions, cross country flights and proficiency hops.

Test pilots in the late 1940s found themselves flying at high speeds with life support and survival equipment not significantly different than the gear worn in open-cockpit aircraft during the 1920s and 1930s. When Air Force Capt. Charles E. "Chuck" Yeager exceeded Mach 1 for the first time, he was wearing a standard-issue flight suit, boots, oxygen mask and parachute. In the 1940s, pilots still wore leather flight helmets, which did little more than keep their earphones in place. To protect himself should the X-1 go out of control, Yeager scrounged up an Army tanker's helmet that was heavily padded and provided limited protection. He wore this on his Mach 1 flight. It was not until the end of the 1940s that the first fiberglass hard-shell flight helmets were issued.

Charles E. Yeager in the late 1940s. He is wearing a standard flight suit, seat parachute, and holding a hard shell helmet. The flight suit was made of cotton and would burn. The later nylon flight suits were quickly removed from service, as they would melt and stick to the pilot's skin, causing severe burns. The hatch in the side of the X-1 was useless for an in flight escape, as it was forward of the wing. *Air Force photo*

Charles E. Yeager and Arthur "Kit" Murrey and the X-1A. Both are wearing the early partial pressure suits. These provided protection should the cockpit depressurize, but were very uncomfortable. *Air Force photo*

These were not the only shortcomings in pilot equipment. Before World War II, anything above 10,000 feet was considered "high altitude." During the war, this definition was greatly expanded. Reconnaissance aircraft began reaching altitudes higher than 40,000 feet. Pilots could see the curvature of the Earth's horizon below, while above the sky was a deep blue-black. Above this altitude, the atmospheric pressure was too low for human survival, even with a supply of breathing oxygen. It was necessary for the cockpit to be pressurized and for the pilot to wear a pressure suit.

The X-1 series and the Douglas D-558-II Skyrocket were the first aircraft to reach altitudes at which a pressure suit was required. These early suits were adequate but very uncomfortable. The early versions were called "partial pressure" suits. They resembled a tight-fitting flight suit made of heavy fabric and had tubes running down the pilot's arms and legs and that literally squeezed the pilot. Should the cockpit lose pressure, the tubes would inflate, drawing the fabric even tighter. This protected the pilot against the effects of depressurization.

The suit was tight even when depressurized. It lacked a cooling system. The pilot's own body heat would build up, causing him to perspire and leaving him soaked in his own sweat. It was not unusual for a pilot to lose several pounds during a long flight. Despite its shortcomings, however, the suit soon proved its worth. On August 25, 1949, Air Force test pilot Frank K. Everest Jr. was making a flight in the X-1 when he lost cockpit pressurization at 69,000 feet. This event marked the first operational use of a partial pressure suit to save a pilot's life.

Aircraft escape systems of the period also were deficient. Pilots of early U.S. and British jets had to open the canopy and climb out in an emergency, the same procedure as had been used since World War I. The pilots of the X-1 series aircraft faced the same problem. The original Bell Aircraft X-1 had a hatch in the right side of the cockpit through which the pilot would enter once the B-29 launch aircraft took off. The hatch was useless for escape during an in-flight emergency, however. It was located directly in front of the wing's leading edge, and the pilot would be struck if he tried to jump. The

later, second-generation aircraft, the X-1A, X-1B and X-1D, were fitted with a conventional canopy design but the pilot still had no choice but to make his escape by jumping over the side.

During World War II, a few Nazi German fighters had been equipped with crude ejection seats. Following the war, ejection seats began to be fitted into production jet fighters. The ejection seats of this era had limited operating envelopes. An ejection at low altitude and/or low speed would not allow the pilot enough time to open his parachute before hitting the ground. Problems also existed at the upper end of the performance envelope; at supersonic speeds, an ejection would subject the pilot to a violent wind blast.

Given the shortcomings with ejection seat technology, and the difficult environments of high-speed/high-altitude flight, some argued the obvious: a different approach was needed. This took the shape of a capsule system. The D-558-I, D-558-II and the Bell X-2 all featured a nose capsule designed to separate in an emergency. Pilots for both the Air Force and the National Advisory Committee for Aeronautics (NACA) who flew these aircraft, however, had little faith in the nose capsules' usefulness in an emergency.

NACA pilot Stanley Butchart had this to say about the D-558-I capsule: "They had a piece of paper showing us the speed and altitude envelope where you would be safe to get out. You got out of those things by pulling one handle which dropped the nose of the machine off -- then another handle that would release your little back rest and you kind of crawled out the back. That's not much of a way to get out of an airplane when you're in trouble. The envelope was rather restricted too as far as speed and altitude. When you stop to think of it, [at] the higher speeds, and you drop the nose off, you're going to get a very big negative g as you come out of there. So that restricts you as to how fast you can be going and still use that escape method. We would look at that and kind of throw it in the back of the desk and go on about our work."

NACA pilot Scott Crossfield, who flew both the D-558-I and –II, was even more critical, noting: "...this is the way to commit suicide, to keep from getting killed. They never did have the development on them that they should have had, and they weren't any good anyway. If you could make a capsule that was good enough to live through the emergency, you might as well fly it and throw away the airplane." The shortcomings he and Butchart saw with capsule escape systems became a tragic reality during the early years of high-speed flight.

Howard Lilly was killed in a crash of a D-558-I on May 3, 1948. Lilly had just lifted off the Edwards lakebed when witnesses saw a large section of the fuselage skin separate from the aircraft, followed by smoke and flames. The D-558-I wallowed in flight for a few seconds, then began a left yaw and roll and dove into the lakebed. Lilly was killed on impact. The crash investigation showed that the compressor section of the plane's jet engine had failed. This sent chunks of the compressor housing and broken turbine blades out the side of the aircraft, cutting the control cables and fuel lines. Flying too low for the capsule to be of any use, Lilly never had a chance.

The X-2 also was fitted with a capsule system. Designers envisioned that in an emergency, the X-2 pilot would separate the capsule from the rest of the vehicle's fuselage. A static line would deploy the stabilization chute attached to the back of the capsule. This would maintain the capsule in a nose-down attitude, and begin slowing it to a terminal velocity of 120 miles per hour. Once the capsule had slowed and was below an altitude of 10,000 feet, the X-2 pilot would jettison the canopy, climb out of the cramped cockpit and open his parachute.

Many found fault with the concept. Everest shared the low regard of his NACA pilot counterparts toward capsule escape systems, noting that the separation would subject the pilot to a negative 14g acceleration. As the pilot's pressure suit helmet was nearly touching the X-2's canopy, he would almost certainly be knocked unconscious. Everest viewed the capsule design to be unsatisfactory and would

never have used it except in a dire emergency due to the extreme g forces to which he knew he would be subjected.

Air Force test pilots Iven Kincheloe (standing) and Mel Apt with the X-2 at Edwards AFB. The small size of the capsule meant that Apts' knees were even with the cockpit railing. When the bulk of a partial pressure suit was added, the pilot could barely fit into the aircraft. In the event of an emergency, an X-2 pilot would have to climb out of the falling capsule, and parachute to a landing. ***Air Force photo***

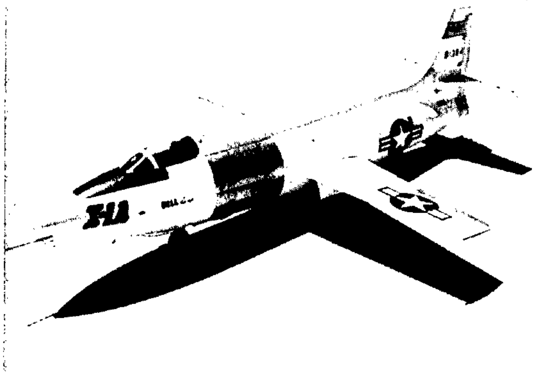
Beyond the issues of antiquated survival equipment and the deficiencies in escape systems, there were much more basic differences between flight safety conditions then and now. Simply put, present-day safety procedures and risk assessment concepts would not have been understood by pilots and engineers of the 1940s and 1950s. This is due in part to the fact that they lived in a different time, when aircraft accidents were far more common and the risks both less understood and more acceptable. Procedures at that time were geared to propeller aircraft but were being applied to flight testing of high-speed jets and supersonic rocket planes. The more significant differences, however, were with the tools, knowledge and experiences we have today but which had yet to be developed in the early years of the jet age. Just as the technology of aviation had to evolve to meet the demands of the postwar era, so too did flight planning, training procedures and data processing.

In the 1940s and 1950s, there were two competing philosophies of research flight planning. The first, which was based on systematic, incremental speed and altitude build-up, was favored by the NACA. Typically, speeds during NACA research flights would be increased by only a 0.1 Mach number on each flight. This approach resulted in an extraordinarily good safety record for the NACA. Between its founding in 1917 and Lilly's death in 1948, no NACA pilot was killed during a research flight. The NACA approach was to collect the most complete and accurate data possible, with the time required to collect that data a secondary consideration. Setting speed or altitude records was not an issue.

The Air Force favored an alternative philosophy that valued speed over thoroughness and reflected the rapid advancements of aviation technology in this period, the demands of the Cold War and the political imperative of attaining speed and altitude records. Flights were made with jumps in Mach numbers of 0.5 or greater. This expedited flight test approach reflected the Air Force's operational focus, as compared to the NACA's research priorities. The Air Force was in the midst of being transformed into a service branch based on jet-powered and supersonic aircraft. It needed flight-ready aircraft as soon as possible. If flight characteristics had shortcomings, the thinking went, these problems could be corrected in later production versions of the aircraft.

At the NACA Flight Research Center (now the NASA Dryden Flight Research Center), goals could be shaped by input from other NACA centers such as the Langley Research Center in Virginia or the Ames Research Center in northern California, based on the centers' research activities. Input also might come from military services, or from contractors or from Dryden center chief Walt Williams. There were no designated flight planners in the 1940s or 1950s. Project engineers did their own mission planning, and would establish whatever procedures they thought necessary to obtain the data they sought. Equipment needed to carry out a mission would be fabricated in a machine shop. The engineers would indicate what they

needed, and technicians would devise ways of building it. No paperwork was needed.



The X-1A after being turned over to the NACA. One of the first modifications made to the aircraft was the addition of an ejection seat. *NASA photo*

After each flight, data would be worked up and analyzed for any indications of dangers ahead. If any were suspected, the flight might be repeated to be sure the warning was valid. The flight plan would include "off-ramps" – contingencies such as alternative flight plans or emergency procedures – so the pilot would know ahead of time what to do if problems arose during the flight.

In the Air Force, there was, officially, a chain of command regarding test flights. In late 1953, when Yeager reached a speed of Mach 2.44 in the Bell X-1A, Gen. Al Boyd, commander of the Air Research and Development Command at Wright-Patterson Air Force Base in Ohio, had ultimate responsibility. The "approving official" was Brig. Gen. J.S. Holtoner, commander of the Air Force Flight Test Center (AFFTC) at Edwards, who had the go/no go authority for the flight. Everest was Yeager's immediate superior and would have signed off on the flight as well.

The reality, as Yeager recalled some three decades later, was more causal. He wrote: "By now these rocket research flights were so routine that [Capt.] Jack [Ridley] and I were on our own, pretty well free to do our own planning and flight profiles with neither NACA nor the Air Force looking over our shoulders. General Boyd, for example, was back at Wright, taking charge of a missile development program. And the NACA guys now had their own test flight program and could care less about ours."

In practical terms, both these approaches meant that those who planned the flight were also the ones assessing the mission's safety. Without the tools and procedures of today, however, they had little to go on. One major source of data was wind tunnel testing performed during development of the aircraft. When Yeager and Ridley planned the high-speed flights in the X-1A, they knew based on wind tunnel data that the aircraft had reduced stability at speeds in excess of Mach 2.3. The issue facing them was not the ability of the X-1A to reach high speeds; with a turbopump and increased fuel supply the aircraft could easily exceed Mach 2. Rather, it was the issue of stability. This was something they felt could be dealt with. As speed increased, they reasoned, Yeager would simply avoid any rapid control movements. Ultimately, during this time, decisions about the level of risk, and whether or not it was acceptable, were based on engineering experience as well as analytical and emotional judgments.

But this was also a time when many unknowns lurked to trap the unwary pilot. The flights faced aerodynamic phenomena that had not yet been experienced due to new aircraft designs and the speeds they were capable of reaching. The mass of conventional piston aircraft was evenly distributed between the fuselage and wings. The demands of high-speed flight altered this in the post-war generations of aircraft, in which the mass of the engines, fuel and other equipment was now concentrated in the fuselage.

Yeager and other X-1A personnel were not aware of another, far more dangerous threat. In December of 1953, "inertial coupling" was only a theoretical concept. One reason the concept was unknown was its subtlety. Inertial coupling was triggered by a combination of an aircraft's mass distribution, speed and roll rate. These change over the course of a flight as fuel is burned and the aircraft is operated at different altitudes, performing different maneuvers. As long as these factors are *not* at the critical values, no adverse effects will occur and the

aircraft will behave normally. If the conditions *are* met, however, the results are catastrophic.

Yeager was the first to encounter the phenomena, on his Mach 2.44 flight in the X-1A. The first sign of trouble occurred as the aircraft began its speed run at 76,000 feet. Yeager noticed the X-1A beginning a slow roll to the left. He responded by applying aileron and then rudder to stop the roll. The aircraft did not stabilize but began a more rapid roll to the right. When Yeager attempted to counter this, the X-1A abruptly reversed direction into a fast left roll. Yeager shut down the rocket engine and the X-1A tumbled out of control at a speed of Mach 2.44. The aircraft made several complete rolls in one direction followed by several in the other. Yeager said later that during one roll he was looking at the Palmdale area, and then on the next he could see the mining town of Boron. From his position to the north and west of Edwards the two areas were 45 degrees apart.

Unless Yeager got the aircraft back under control, he would not survive. The X-1A lacked an ejection seat. During the violent tumbling, Yeager's head hit the canopy so hard that his helmet cracked the Plexiglas. The battering caused him to black out several times. With Yeager incapacitated, the aircraft fell some 50,000 feet, slowing to subsonic speed in an inverted spin. Yeager revived and was able to recover the X-1A first into an upright spin, then into normal glide flight. Despite being groggy from the tumble, at low altitude and without a chase plane Yeager was able to land successfully on the lakebed.

The ability of a pilot to prepare himself for a risky flight was limited. The first computerized flight simulator used at what is now Dryden was the Goodyear Electronic Differential Analyzer (GEDA). This was an electromechanical analog computer that used different voltages to indicate the values of specific qualities such as speed, altitude or attitude. At the time, digital computers existed but were too limited in speed and capabilities to do real-time simulations.

Initially, the GEDA was used to analyze aircraft flight maneuvers. However, its ability to reproduce an aircraft's handling in real time made its value as a pilot simulator obvious. The first aircraft to make use of the GEDA as a simulator was the Bell X-2. NACA engineers Richard E. Day and Donald Reisert modified the GEDA with the X-2's equations of motion and its aerodynamic and physical characteristics. This was done not with software programs but by setting rotational resisters connected with plug-in wires. A strip chart with six or eight pens recorded the data. The mechanical nature of an analog computer is reflected in the related nomenclature. Day and Reisert were called "programmers," but an analog computer was said to be "mechanized."

The GEDA filled several roles in the X-2 program. These included not just pilot training but also obtaining aerodynamic data, extracting derivatives and flight planning. Engineers would "fly" the simulation to the next planned Mach number and then write a flight plan to obtain data at that point. The process would be repeated for each data point until the flight envelope had been fully expanded. The X-2 pilot also could practice a mission on the simulator, to become familiar both with its requirements as well as with potential dangers and to practice emergency procedures.

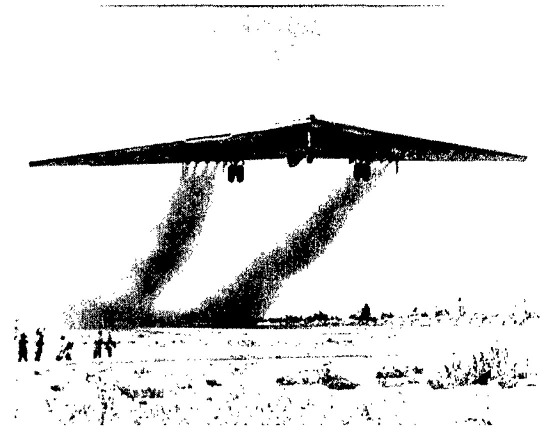
The X-1B simulator in 1958. The display is a cathode ray tube, while the cockpit is a large wooden box. ***NASA photo***

The capabilities of the GEDA, however, were limited. A full simulation is called "6 degree of freedom (6 DOF)." These are movements around the yaw, pitch and roll axes; climb/dive, sideways and speed up/slow down. The GEDA lacked the capability to do a full 6 DOF simulation. It could do either a 3 DOF (yaw, pitch and roll with the other parameters fixed) or a 5 DOF for stability and control data with the speed/Mach number fixed. For the X-2 simulations, an iron pipe with centering springs was initially used as the control stick. Control position transducers translated the stick's movements into control surface inputs for the computer. (The X-2's rudder was locked at supersonic speeds, so this control surface was not included in the simulation.) The display used a cathode ray tube that showed a wing as viewed from behind. This allowed the simulator pilot to see sideslip, angle of attack and roll of the "airplane."

The newness of the simulator concept, along with the limitations of the analog computer, caused some pilots to doubt the simulator's realism. NACA engineers used data from the early X-2 flights to program the simulator. Based on this, the simulator showed that at speeds above Mach 2.4 the X-2 would become unstable due to inertial coupling when its angle of attack exceeded 4 or 5 degrees. The wings would not remain level, and aileron inputs to level the wings would exacerbate the situation until the aircraft would tumble out of control.

When X-2 project pilot Everest saw what the computer was indicating, he declared the simulation no good. At a subsequent meeting between the Air Force and NACA engineers, Col. Horace A. Hanes, director of Flight Test and Development at the AFFTC, strongly suggested to Everest that he go back and fly the simulator again. Everest did so, and was soon a believer in flight simulations. On his final X-2 flight, Everest reached a maximum speed of Mach 2.87, becoming the fastest man alive. After engine shutdown, he held the X-2's angle of attack at nearly zero degrees until the aircraft had slowed to Mach 2.2. Only then did Everest begin the turn back toward the Edwards lakebed.

While the GEDA could provide training and warn of potential dangers that loomed during a flight, a test pilot still had little in the way of outside help during a mission. Although chase planes were used, many test flights were still flown as solo missions. The loss of the YB-49, in which Capt. Glen Edwards and his four-man crew were killed, was an example of a situation in which the pilot was left to his own devices. The flight was made on a Saturday so no chase plane was available. The first indication the flying wing had crashed was when the smoke plume from the post-crash fire was reported. There was no radio distress call. As a result, the exact cause of the crash is not precisely known.



The YB-49 flying wing bomber taking off. Although a sleek and futuristic looking design, the YB-49 had severe technical and stability problems. The loss of one of the aircraft, along with Glen Edwards and his crew, remains a mystery to the lack of a chase plane on the final flight. *Air Force photo*

Chase planes supported the rocket planes' flights during launch and landing, but for the bulk of the missions, research pilots were on their own. Flight data was recorded on board using film. This would have to be developed after the airplane landed and then measured and turned into charts and graphs by the (human) computers. The only real-time data on the aircraft was supplied by radar tracking equipment in a van parked on the lakebed. The radar data showed the plane's position relative to the lakebed but was not relayed to the pilot. He had to find his own way home. No control room

existed in the 1940s and 1950s to monitor the aircraft systems in real time.

The last flight of the X-2, resulting in the death of Capt. Milburn G. Apt, underlined the limitations of flight planning procedures used in the mid-1950s, the dangers of trying to achieve speed records, the shortcomings of existing survival equipment and the technological demands inherent in the speeds and altitudes being reached. The chain of events which resulted in the X-2's crash began when Everest, the most experienced rocket pilot the Air Force had at that time, was assigned to attend Armed Forces Staff College. He made his last flight in the X-2 on July 23, 1956, reaching a speed of Mach 2.85. Everest had made all of the powered flights, and his impending transfer would leave the program without a pilot. A pair of replacement pilots had been selected in February 1956 to fill the gap. They were Capt. Iven C. Kincheloe and Apt.

Kincheloe made his first X-2 flight on May 25, 1956, reaching a speed of Mach 1.14. On his fourth flight, on Sept. 7, 1956, he reached an altitude of 126,200 feet. At this altitude, the air density was 1/250th that at sea level, and the dynamic pressure on the aircraft had dropped close to the point where conventional aircraft controls would become ineffective. While a new world altitude record had been set, the first Mach 3 flight had yet to be accomplished.

Time was running out for the Air Force, however. NACA engineers wanted to use the X-2 to study aerodynamic and structural heating, boundary layer flow at high supersonic speeds, noise problems at supersonic speeds and aircraft handling at extreme altitudes and speeds. These studies would expand upon research being undertaken with the NACA X-1B and X-1E rocket planes.

Three more flight attempts were made by Kincheloe but were aborted before the X-2 could be launched. Apt was then selected as the pilot for the Mach 3 flight. The actual orders were that he would fly "the optimum maximum energy flight path." Apt had made training runs in the GEDA simulator and received briefings on July 29, 1956. He was shown the procedure for reducing angle of attack to prevent loss of control. He had also made several other informal simulator runs by Sept. 24. Apt was a fully qualified test pilot with considerable experience gained in earlier inertial coupling flights in the F-100. But he was about to make his very first flight in the X-2, and was being asked to fly faster than any human had ever flown, in an aircraft known to have poor high-speed stability.

Apt would have to minimize the control movements and keep acceleration on the aircraft at 1g or below. Another difficulty he faced was that previous flights had shown the airspeed and altimeter measurements on the aircraft to be unreliable. His chances of actually reaching Mach 3, based on the simulator results, were judged minimal. Even with a full engine burn and a perfect flight path, the best speed expected was Mach 3.05. To help Apt, Kincheloe would fly as chase and coach him through the flight.

The flight was made on Sept. 27, 1956. With Apt in the cockpit, the X-2 was dropped from the B-50 launch plane. He flew the climb profile exactly, then gently pushed over into a shallow dive for the speed run. The rocket engine burned 15 seconds longer than on any previous X-2 flight. At shutdown, the X-2 was flying at 2,060 miles per hour, or Mach 3.2. The aircraft was in a 25 degree bank and a 6 degree dive. The acceleration was 1g , while the angle of attack was plus 1 degree, sideslip was 1 degree to the left and the ailerons were in a nearly neutral position. The Machmeter was still pegged at Mach 3.

It would later be speculated that Apt assumed the reading was inaccurate, and that the X-2 was actually flying slower. Crash investigators also speculated that he was worried the X-2 was too far away from the lakebed and that, unless he turned immediately, he be unable to reach it. In the X-2's tiny cockpit, he could not see Rogers Dry Lake. If this was Apt's concern it was misplaced, tragically, because the lakebed was actually in easy gliding distance.

All that is known for certain is that Apt radioed, "Engine cut, I'm turning." Within 18 seconds,

the X-2 was inverted, and beginning to roll violently. Apt was thrown about the cockpit. With the aircraft still inverted, he attempted to recover but was unsuccessful. Apt triggered the capsule. As Everest had predicted, the capsule's motions during separation were so violent that Apt was knocked unconscious. He revived, but was too low to allow time to jump from the capsule and use his own parachute. He was killed on impact.

Apt had been put into a situation that ultimately proved lethal. He was flying the X-2 for the first time and was attempting to reach its maximum speed. At these speeds, Apt had to maintain a nearly zero angle of attack until he slowed to less than Mach 2.4. But the instruments he used to decide when it was safe to turn were known to be inaccurate. Nor was there an outside source for the speed data. The X-2 was known to have poor directional stability at high Mach numbers and its control system lacked any kind of electronic stability system. Indeed, the control system design used to fly at Mach 3 was little different than that of a World War II subsonic fighter. Apt was left to cope with the pitfalls of the X-2 with only his own skills to survive. Finally, in the face of all these problems, the Air Force had charged ahead to set a speed record.

When the X-15 took to the skies three years later, it ushered in a new mode of flight research. The program involved three partners – the NACA (after 1958, NASA), the Air Force and the Navy. In a break from the NACA's more limited role in earlier X-plane programs, overall technical direction was by NASA. The speed and altitude buildup would be done with a step-by-step approach rather than by making big leaps. If a flight indicated aerodynamic or control problems, the issue would be analyzed and, if necessary, the ensuing flight plans would be altered to examine it. Not until the X-15's characteristics were understood at the far reaches of its capabilities would the next step be taken.

The flight simulator had become central to the X-15 program. There were simulators at North American Aviation, the prime contractor, and at the Flight Research Center, Ames and Langley. At the Flight Research Center, the simulator was used extensively for pilot training. These were not the informal sessions Apt had on the GEDA. The pilot for each X-15 mission underwent some 20 hours of training on the simulator. (The actual flights took about 10 minutes from launch to landing.) This simulator work involved, in addition to practicing the mission plan, running through emergency procedures and alternate mission plans should problems arise during the flight. Engineers also used the simulator to try out flight plans and understand data from earlier flights. The engineers' work with the simulators often went well into the night.

Once the flight planning for the next X-15 mission was complete, a "tech brief" was held during which engineers and the pilot went through mission objectives, go/no go criteria and research and data requirements. This was followed by the crew brief, which was usually held the day before the flight. The crew brief brought together nearly all the operational personnel and research and instrumentation engineers. The group would go through the flight plan, discuss any items remaining from the tech brief and review limitations and mission rules.

Many of the engineers who attended the crew brief would be in the control room on flight day. The X-15's on-board instrumentation radioed data to the ground, where it was displayed on strip charts. The data included dynamic pressure, angle of attack, angle of sideslip and control surface position. Engineers watched the strip charts for any indications of trouble. The X-15's position was displayed on a plotting board. If the engineers spotted anything amiss, they would report it to the ground controller, who was referred to as NASA 1. He was the only person in direct communication with the B-52 launch plane crew, the chase plane pilots and the X-15 pilot. NASA 1 and mission control would be the Earth-bound eyes and ears of the research flight. This was an advantage earlier X-plane pilots had not enjoyed. X-15 pilots would face the unknown, but unlike their predecessors, they would not face it alone.

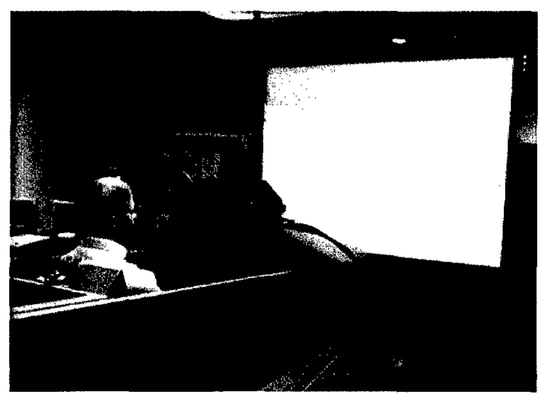
This approach, of a pilot supported by teams on the ground that could address problems in real time, would soon find application in the emerging piloted space missions. The increasing complexity of flight research, particularly the shift to fly-by-wire aircraft computer systems, required new levels of technological review, ground test and validation.

NASA research pilot Neil A. Armstrong following a 1960 X-15 flight. He is wearing a full pressure suit. This not only protected against depressurization, but also from heating and wind blast during a high-speed/high-altitude ejection. This eliminated the need for an escape capsule. *NASA photo*

The hard-won lessons learned over the past half century can be seen in the procedures used today at the NASA Dryden Flight Research Center. Unlike the often casual planning of earlier times, there are now formal procedures established for each step in the development, testing and operation of a new research vehicle. Before metal is cut on a new research aircraft, its design undergoes wind tunnel testing; computational fluid dynamics computer simulations are also made. Such data has uncertainties and variables, and to determine their potential consequences computer simulations are run. These may number thousands of runs, made through different combinations and limits, to identify potential outcomes.

When a research vehicle enters the hardware stage, it undergoes ground testing. This involves several steps, from simply determining whether an individual component works to full end-to-end tests of the completed vehicle. As computer systems are now integral to aerospace systems, the vehicle's software also must undergo extensive testing. A matrix of "fault trees" is developed, covering how a specific system failure would affect the vehicle. Any changes in hardware or software must go through an extensive review and approval process that incorporates input from configuration control and engineering review boards as well as from experts from outside the government.

If the vehicle is piloted, customized flight simulations are developed. This serves not only to train the pilot, but also to test different flight control laws for use in flight planning and to provide warning of potential dangers. The project pilot may spend many long hours, often after the normal workday ends, in the simulator preparing for a flight.



Martha Evans, NASA simulation group leader, in an early F/A-18 simulator. The visual display is wide screen and in color, while the instrumentation reflects the actual cockpit layout. *NASA photo*

When all this is completed, a flight readiness review meeting is held. The engineers in charge of each aspect of the project make a presentation, and then are asked hard questions about the project's status. Review board members then make their recommendations about the project, and what more should be done before the flight is carried out.

The day before a flight is scheduled, the T-1 meeting is held. It brings together the pilots, engineers, control room personnel and support staff. The group reviews the mission plan, abort criteria and other mission requirements so that all are familiar with what is expected of them. On the morning of the flight, there may be a final briefing to cover weather issues and address any last-minute changes.

The personnel now begin final preparations for the flight. The pilots climb into the experimental aircraft and the chase planes. They are dressed in fire-resistant flight suits and gloves as well as helmets. If an emergency occurs, the pilot can fire an ejection seat which will propel him out of the cockpit. The ejection seat can propel a pilot or crewman high enough for their parachute to open no matter if the plane is sitting on the runway or at the aircraft's maximum performance parameters. As the 20 or more belts, hoses, buckles and other connections are attached, the pilot essentially becomes one with his airplane.

As the pilots prepare, the mission control room staff take their places at the consoles. They have the latest set of checklists and contingency procedures. Their video displays show color-coded diagrams of the research vehicle's internal systems – green for normal, yellow for caution and red for a malfunction. Each controller monitors a specific system, and can call an abort if the situation requires it. As today's research aircraft sit at the end of the runway, what is to come next seems almost routine. Almost.

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Saving Lives through Awareness

Ms. Christy Cornette
2006 SAFE President-Elect

Taking over the helm as President of the SAFE Association is both an honor and a challenge. There is a wonderful mix of people and strengths on this year's board that will help guide me. It is my desire to excel in the position as have those who have served before me. I am passionate about the safety, survival, and life support community and feel that everyone in this industry has an obligation not just to ensure safety today, but in the future as well. My board of directors will take all possible steps to ensure SAFE will be a part of that future. SAFE is an organization with intense pride and I want it to have great presence in our industry for many years to come.

Through my many years of involvement, I have found that this is a business that gets in your blood and becomes a large part of who you are. We have jobs that make a difference in people's lives. How great is that! My intention is to focus on making SAFE synonymous with saving lives through awareness. I want it to be a thing of the past for someone in our industry to ask, "What is SAFE?" How do we make this happen? This is where the SAFE membership can be of immense help. We need you to assist the Board in "Getting the Word Out." Alone, the Board of Directors cannot reach the thousands of people that the membership is exposed to daily; both in their work and social arenas. Our members meet people all of the time who should be a part of this organization and have never heard of it. Hand out a SAFE brochure when you travel; inform them of our all-encompassing symposium and invite colleagues to chapter meetings. When bright and innovative new hires join your organization, spur their interest. Our membership is our best marketing tool. It is not only about promoting and sustaining the organization, but the cooperation and technical exchange between everyone that aids in promoting safety as a whole. That is what ultimately saves hundreds, or even thousands, of lives. The feedback of the corporate members as well as our individual members is important to me. I sincerely hope that our entire membership will feel free to approach or contact me with suggestions or concerns.

We dedicate much of our effort to the military but also touch the general public with our knowledge and products. Since the military tends to be our primary focus, I want to make strides to improve military attendance and involvement. The key to safety and survival is largely achieved through awareness, and SAFE provides the forum for spreading that awareness. The world of safety and survival equipment design and maintenance is made up of many brilliant, talented, and motivated individuals that benefit from the networking that SAFE provides. The symposium allows for discussions of equipment deficiencies that lead to design improvements. With SAFE having a strong presence in the community, even more lives can be saved.

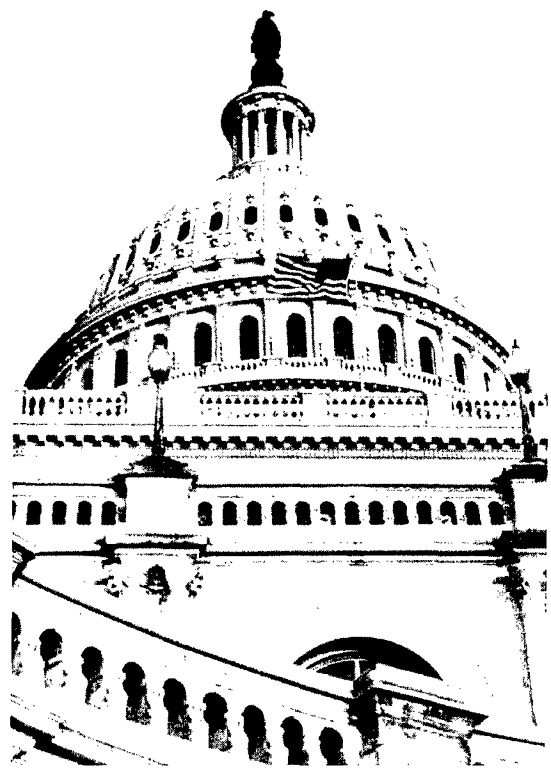
I have worked for the past 29 years at the Naval Surface Warfare Center, Indian Head Division, and my job is to support the warfighter. We provide products to the warfighter that give them combat edge. I am very proud of what we do. Our products assist them in out-maneuvering and out-fighting the enemy and, if all else fails, we are still there for them with rescue and survival equipment. We design, manufacture, qualify, test, procure, and conduct surveillance on these items. Most of the items we support are "man-rated." That means a person's life depends on it working when needed; no second chances. Quality is a priority and a must.

The SAFE Association has provided me with a wealth of technical exposure and opportunities as I'm sure it has for many of you. It gives me great satisfaction and pride to be a part of the SAFE Association and the safety and survival community. Let's together make SAFE an industry word synonymous with saving lives through awareness.

Inside the Beltway: September 7, 2006

Steve Madey
Washington Liaison, Capital Resources, LLC

Background
The feeding frenzy over "pork," earmarks, run away spending and bad behavior by some lobbyists has slowed for a bit, but will get going on a the local level as the '06 Congressional races head into their last 60 days. But for now, with only 19 legislative days left for the second session of the 109th Congress, the conventional wisdom is that the national security-related appropriations bills– Homeland Security and Defense – will be passed and sent to the President before the fiscal year begins.



That's the conventional wisdom. However, recent experience may imply a different outcome, and here's why: the Senate Defense Appropriations Bill is not yet off the floor, and there isn't much time to complete and vote on a conference report nor is there much pressure for immediate action because of the effect Supplementals have had- more on that later.

A favorite "hot button" issue in the press has been the push for more transparency in spending bills, including naming names. That is, earmarks would be attributable to specific members. Oh, horrors! Not that! Think about this – members publish press releases taking credit for their work and send those releases back to their home districts, where they rightly take credit for helping local causes and projects. It's really not too much of a secret who did what…

More important than what the popular press covers has been a more substantial battle between the administration and the congress of supplemental spending. Supplemental spending generally does not "score" as spending – it is categorized as "emergency" and is not subject to review of the authorizing committees. Supplementals fund ongoing operations in the Global War on Terror and other things, such as Katrina relief.

Defense supplementals have become a regular way of life and generally give the administration wide latitude in how to spend the funds. Procurement and even R&D have been creeping into supplementals under the guise of refitting returning units. The current supplemental includes $68 billion (or sixty eight thousand million dollars) for DOD, in addition to the regular FY 07 request for $ 517.682 billion.

A case can be made for DOD supplementals – wartime requirements can't be predicted years in advance and the regular planning and budgeting process takes more than a year from inception to presentation to congress, and then there's another eight months to year before the bills are passed and signed so the funds become available. Still, continued use of such large supplementals removes some congressional discretion – not a bad thing in some views, but an increasing irritant to the congress. My guess is that things will continue along as in the past few years, but the coming election could affect the way ahead.

The Situation

The Defense Subcommittee of the House Appropriations Committee (HAC-D) has marked up their Fiscal Year 2007 spending bill and sent it to full committee for action, and passed it on the floor of the House as HR 5631 on the 20th of June by a vote of 407 to 19. That bill awaits completion of the Senate version of the bill, so that the two houses can convene a conference to iron out their differences and draft a conference report to be voted on both houses and sent to the president.

Meanwhile, the House Defense Authorization Bill (HR 5122, with details in House Report 109-452) has been marked up and passed in the House on May 11th and the Senate has passed its version under the heading of S. 2766, with details in the Senate Report 109-254. Both houses are now in conference on the Defense Authorization Bill for FY '07.

Additionally, there have been a series of hearings on Homeland Security that yield more congressional direction on what should be bought with Homeland Security funds.

What's Likely Next

So far the only thing that is for sure is the election scheduled for November 6th. We know this cannot slip. Less certain is whether the Defense Bills are enacted and signed before the election. If so, we would consider this great. However, the biggest effect of not having the FY 07 Defense legislation in place is that spending levels would likely be reduced to a percentage of '06 levels and no new program starts would be allowed. There would be adequate operating funds through the supplementals but overall the outlook is bleak.

That's all for now. Please don't hesitate to call if you have any questions or I can be of assistance. We are here to serve. If you find yourself in the Washington area, please stop by and visit.

SAFE Association Chapters - Current Status

Marcia Baldwin
2006 Chapters Chairperson

SAFE Association is currently comprised of ten regional chapters, with seven of these expanding across the United States, and the remaining three representing Europe, Canada and Japan. Each regional chapter takes on a life of its own, reflecting the local industry and culture, and ultimately shaping each into a unique body while all serving in the greater interest of preserving human life through enhancing safety equipment.

2006 has been an exciting year for the SAFE Chapters. In addition to local chapter meetings, there were several events this year involving multiple chapter involvement, including joint chapter meetings, activities surrounding industry events and the co-location of SAFE Board meetings with those of the chapters. The following is a brief highlight of these special events:

SAFE ***Europe Chapter*** flexed their membership strength with a smashing hit with their symposium held in Warsaw, Poland, March of this year. Their chapter is known for producing quality technical resources which will be included in the SAFE Association Symposium held this October in Reno, Nevada. We are fortunate to have this technical resource in our organization.

Alamo Chapter enjoyed the successful hosting of U.S. Air Force Industry Day in San Antonio, Texas, in April. In conjunction with Industry Day was an Alamo chapter social as well as SAFE Association Board (BOD) meeting.

East Coast Chapter held a meeting and social during the Army Aviation Association of America (AAAA) at the Opryland Hotel in Nashville, Tennessee in April. By co-locating with Quad A, membership attendance was strong at both the meeting and social.

The Navy Fleet Maintainers Conference held in Las Vegas, Nevada, in June proved to be fertile ground for SAFE participation. ***East Coast Chapter*** held a social during the conference in conjunction with NavAir PMA 202, and SAFE Association BOD also held a quarterly meeting.

July was a busy month with ***Alamo Chapter*** hosting a social at the U.S. Air Force Worldwide Survival Equipment Conference in San Antonio, Texas.

Also in July, ***Wright Brothers Chapter*** participated in the Dayton Air Show by supporting special events including Students Open to Aviation Research (SOAR) which offers youth the opportunity to engage in career exploration and educational activities. The Chapter also worked with the Aerospace Adventures program (A2) which provides over 40 interactive, hands on activities, experiments, and demonstrations to the public.

Canadian and East Coast Chapters held a successful joint meeting and social in August. Co-locating in beautiful downtown Ottawa, Canada, joint membership attendance was strong and all enjoyed their stay. In conjunction to the chapter events, SAFE Association BOD also held a quarterly meeting.

While there are many other chapter activities not mentioned here, we appreciate all of our Chapters for their dedication and hard work in growing membership, as well as in expanding areas of transportation safety. Thank you for your efforts.

Information for Journal Authors

Initial Manuscript Submission: Original manuscripts must be submitted double spaced to the SAFE Office at the following e-mail address: safe@peak.org, and include all figures and pictures. SAFE retains the sole decision right to publish submitted information or request edits. Articles that have appeared in the SAFE Symposium Proceedings are acceptable for submission to the Journal, in the proceedings format. The choice of reviewers remains the sole responsibility of the editor if the author requests peer review.

Title Page: The first page shall contain the complete title of the manuscript, names of authors and their company/institution addresses, including phone and FAX numbers of the responsible author.

Abstract: The second page shall consist of an abstract of a maximum of 200 words that summarizes the information in the manuscript without literature citations.

Text: The main composition of the manuscript shall exhibit sound technical writing in English using the general style of the Journal. A manuscript template is available on the SAFE website, www.safeassociation.org under Publications. Articles in the R&D section normally are subdivided into introduction, methods, results, and discussion.

Illustrations, tables, and photographs: Illustrations and photographs are considered figures and shall be so labeled, numbered in sequence as they appear in the text using Arabic numerals. Illustrations will be original or clear copies. Photographs will be glossy photographic or computer-generated prints. Tables will be so labeled, numbered in sequence using Arabic numerals. Legends will be of sufficient explanatory detail as to provide sufficient information without reference to the text.

References: Only references important for the reader should be used to a maximum of 25 per manuscript. In the text, references should appear as numbers within parentheses at the end of the appropriate sentence. In the References section, references should be listed alphabetically. Journal articles should be referenced last name of the first author, initials; initials and last names of each co-author; title of article with only first letter of the first word capitalized; name of journal (using abbreviations of Index Medicus); volume; pages; and year. Book references should be as above for journals including the title and number of chapter cited as the journal title. The book title should follow underlined with the first letter of each word capitalized; book editors (last name first); publisher; city of publication; pages cited; and year.

Mathematical Expressions: Use symbols for engineering terms as published in IEEE publications and for physiology terms as found in publications of the American Physiological Society. Metric units of measurement are preferred with mmHg for gas and blood pressure acceptable. Equations should be numbered consecutively with the numbers in parentheses on the same line as the equation at the right margin.

Footnotes: Footnotes should be indicated by consecutive superscript numbers in the text. Their explanation should be listed at the base of the column of the text were used.

Biographical Sketch: Biographical sketches of each author and co-author for a maximum of the first three authors is allowed, but not required. These should be brief and without photographs. Pertinent information about the author that allows the reader to evaluate their level of expertise and their contact information is acceptable.

Final Manuscript Submission: Upon acceptance of the manuscript for publication in the SAFE Journal, a final manuscript using Microsoft Word must be submitted to the above e-mail address in final form, as it will appear in the Journal. Times New Roman 10 (PC) or Times 10 (MAC) font is preferred using two columns per page. Do not number the pages. Figures and Tables should be inserted in the text where appropriate. At the base of the first column on the first page must be a statement of the date that the manuscript was received by the editor and the date that it was accepted for publication. This information is obtained from the editor upon acceptance of the manuscript for publication. Detailed information on developing a final manuscript for publication, including a format template, is available on the SAFE website, www.safeassociation.org under Publications.

SAFE Association Membership Application

This form is for individual membership in the SAFE Association. Please PRINT or use a typewriter to complete this form.

Send mail to: ☐ Home Address ☐ Office Address

Mr/Mrs/Dr/Rank	Last Name	First Name	MI	SAFE Association File Number

Home Address	City	State	Zip Code	Country

Job Title	Company Organization	Department	Mail Code

Business Address	City	State	Zip Code	Country

Business Telephone	Fax Number	Home Phone	E-Mail

University or Training Institution	Degree or Diploma	Major Area of Study	Year

Check one block to indicate your economic sector.

- ☐ CC Commercial/Non-Defense
- ☐ CD Commercial/Primarily Defense
- ☐ GM Government/Military Organization
- ☐ GA Government/Civilian Agency
- ☐ GL Government/Legislative or Executive
- ☐ GJ Government/Judicial or Enforcement
- ☐ PI Public Interest, Association, or Union
- ☐ RU Retired or Unemployed
- ☐ ST Student

Check one block to indicate your job function

- ☐ AP Acquisition/Procurement
- ☐ DP Director/President/CEO/VP
- ☐ EL Educator/Librarian
- ☐ EN Engineer
- ☐ IN Investigator
- ☐ JO Journalist
- ☐ MN Maintainer/Logistician
- ☐ MA Manager/Administrator
- ☐ MS Marketing/Sales
- ☐ OC Operator/Crew
- ☐ PN Physician/Nurse/Medical Technician
- ☐ SC Scientist
- ☐ SA Staff/Advisory - Legal, Financial, etc.
- ☐ TE Technician
- ☐ OT Other ____________________

SAFE Chapter affiliation or interest ______________

Check one block to indicate your organization's business

- ☐ 01 Aerospace Vehicle
- ☐ 02 Automotive/Land Vehicle
- ☐ 03 Business - Financial, Legal, Sales, etc.
- ☐ 04 Construction
- ☐ 05 Consulting and Analysis
- ☐ 06 Education, Libraries, Academia
- ☐ 07 Electronic Systems
- ☐ 08 Interest Groups
- ☐ 09 Materials or Components Supplier
- ☐ 10 Media
- ☐ 11 Nautical Vehicle
- ☐ 12 Power/Fuel Research
- ☐ 13 Research, Test and Evaluation
- ☐ 14 Safety Equipment
- ☐ 15 Simulation/Training
- ☐ 16 Transportation
- ☐ 17 Other ____________________

Check one block to indicate your personal interest.

- ☐ 18 Engineering
- ☐ 19 Environmental Quality
- ☐ 20 Life Sciences/Human Factors
- ☐ 21 Management/Administration
- ☐ 22 Marketing/Sales
- ☐ 23 Medical/Health Care
- ☐ 24 Occupational Health and Safety
- ☐ 25 Physical Sciences
- ☐ 26 Education/Training
- ☐ 27 Other ______________________

Individual Dues are $60.00 annually / Full-Time Students $10.00 (ID required).
Please endorse this application and send check to:

SAFE ASSOCIATION
Post Office Box 130
Creswell, OR 97426-0130

Applications Signature	Date	Endorsement by SAFE Member	Date

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